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Metals and Alloys

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Articles

Aluminum Alloys in the Railroad Industry 1
A. H. WOOLLEN

Silicon Carbide Additions to Cast Iron 8
JOHN A. BOYER

Gas Carburizing with Pure Propane 13
F. P. PETERS AND M. G. FARRAR

Improving Aircraft Propellers by Surface Rolling ... 18
G. SACHS

Endurance of Gold and Quenched Dental Alloy 24
R. H. LAUDERDALE, R. L. DOWDELL AND K. CASSELMAN

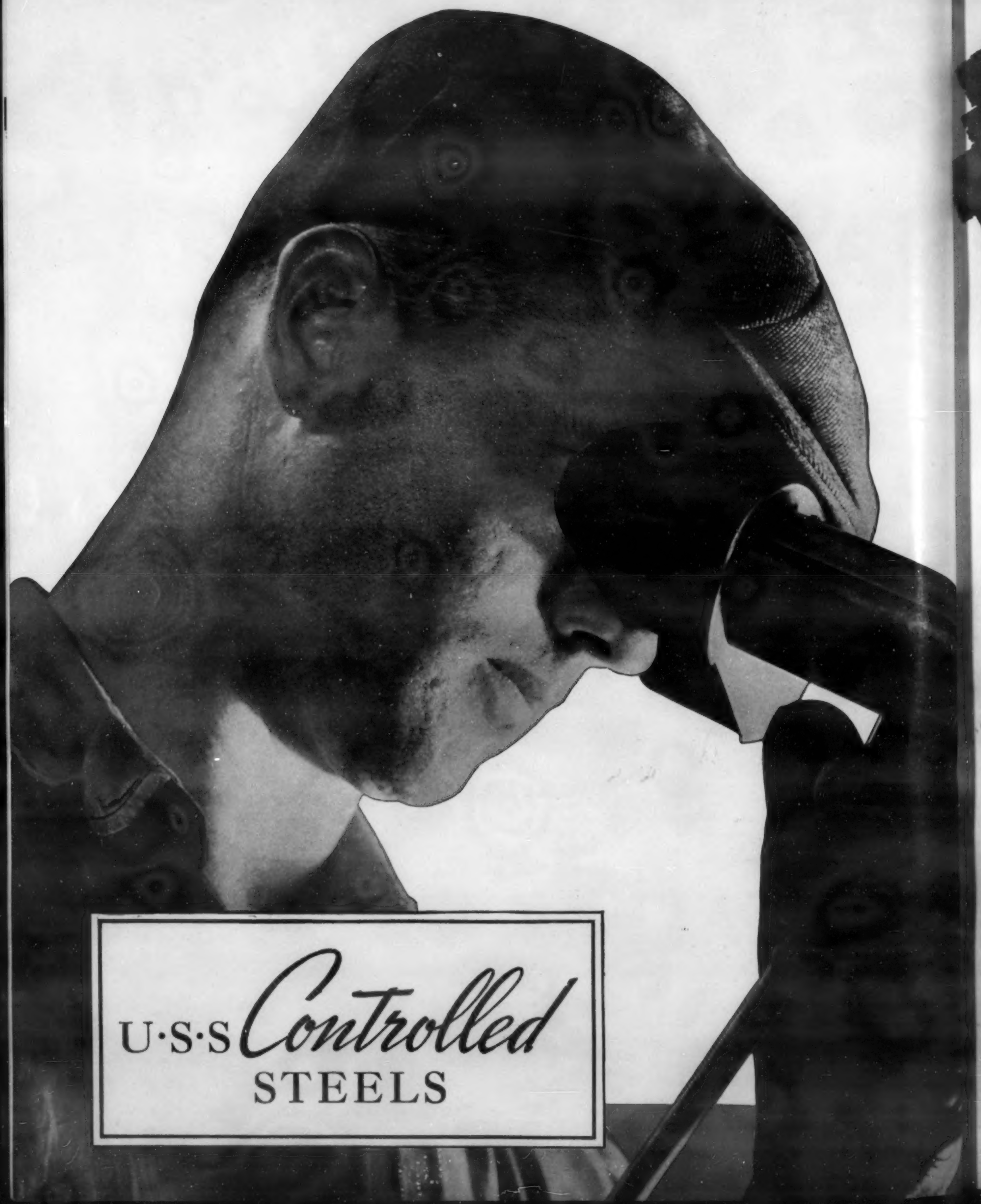
Effect of Very Small Additions to Transformer Steel 26
W. S. MESSKIN AND J. M. MARGOLIN

Manufacturers' Literature . . . . . A 6
Highlights . . . . . A 15
Editorial . . . . . A 17
New Equipment and Materials . . . . . MA 1
Book Reviews . . . . . MA 62
Current News . . . . . MA 64
Trends . . . . . MA 70

Metallurgical Abstracts

Ore Concentration . . . . . MA 14
Reduction . . . . . MA 15
Melting, Refining and Casting . . . . . MA 16
Working . . . . . MA 22
Heat Treatment and Heating . . . . . MA 24
Welding and Cutting . . . . . MA 34
Finishing . . . . . MA 39
Testing and Control . . . . . MA 43
Metallography . . . . . MA 49
Properties and Applications . . . . . MA 53
Corrosion and Wear . . . . . MA 58
General . . . . . MA 60

Paid to bite



U·S·S *Controlled*
STEELS

What is a Metal?

A friend asked us the other day, "How do you define the words 'metals' and 'alloys' that form the title of the journal?" Fortunately the question was "how do *you* define," not "how *are* they defined," or "how *should* they be defined." Hence we are spared the necessity of consulting a lot of dictionaries or getting up a correlated abstract to assemble the definitions that have been given by scientists. This is fortunate, for we think a statement of the way the average metallurgical engineer or metallurgist appears actually to use a word in daily conversation and in informal writing is at least as usable as any lexicographer's definition, or any highbrow scientist's phraseology. Let's tackle the alloy definition another day, and this time stick to "metal".

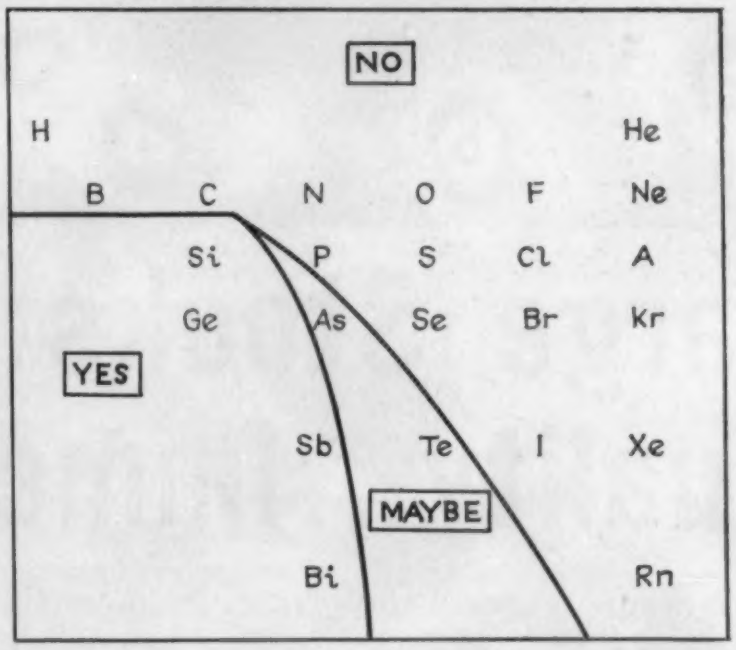
We'll try to state what the word means to us without opening a book to check up on what it means to anyone else. Here goes.

A pure metal is a chemical element which has at least some of several properties, which may be commented upon in order. The true metals have high electrical and thermal conductivity, which can be quantitatively measured. A big gulf exists between the conductivity of true metals and of non-metals. A qualitative difference is the ability of a metal mass to reflect light, from a smooth or polished surface, with the effect of lustre and absence of any feeling of transparency. This is one of the first criteria when we look at a metal but some compounds like galena, films of certain dyes, some glazes and some birds' feathers give much the same effect. A material with a metallic lustre that is malleable as well, is pretty sure to be a metal, but some metals, at least in the purity in which we ordinarily see them, may be brittle. All solid metals are crystalline, and with the exceptions of Hg and Ga they are all solid at room temperature.

Thus we may exclude the gaseous elements on that score, and similarly exclude I because of its similarity to F, Cl and Br, and by excluding C, P, and S on the basis of lack of metallic lustre, have left only As, Sb, Bi, B, Si, Ge, Se and Te to worry about. Of these we think of Si as pretty much a full fledged metal, though there's some funny business about its electrical conductivity that makes us suspect that it isn't quite a metal at all times, and we have to admit that sometimes Ge falls from grace a bit when it resembles Si more than Sn. Antimony strikes us as a reasonably metallic element, and Bi as even more so, while As is less so. Selenium is too much like S to be classed as metallic, while Te isn't quite so far from a metal. Boron is so much like C that we'll class it as a non-metal.

One common characteristic of these borderline elements is that they tend to form quite definite compounds with the regulation metals. Carbides, borides, arsenides, selenides and tellurides and, to a lesser extent, silicides, antimonides and bismuthides tend to be formed, one might say, under less provocation than is required to form definite compounds between two regulation metals.

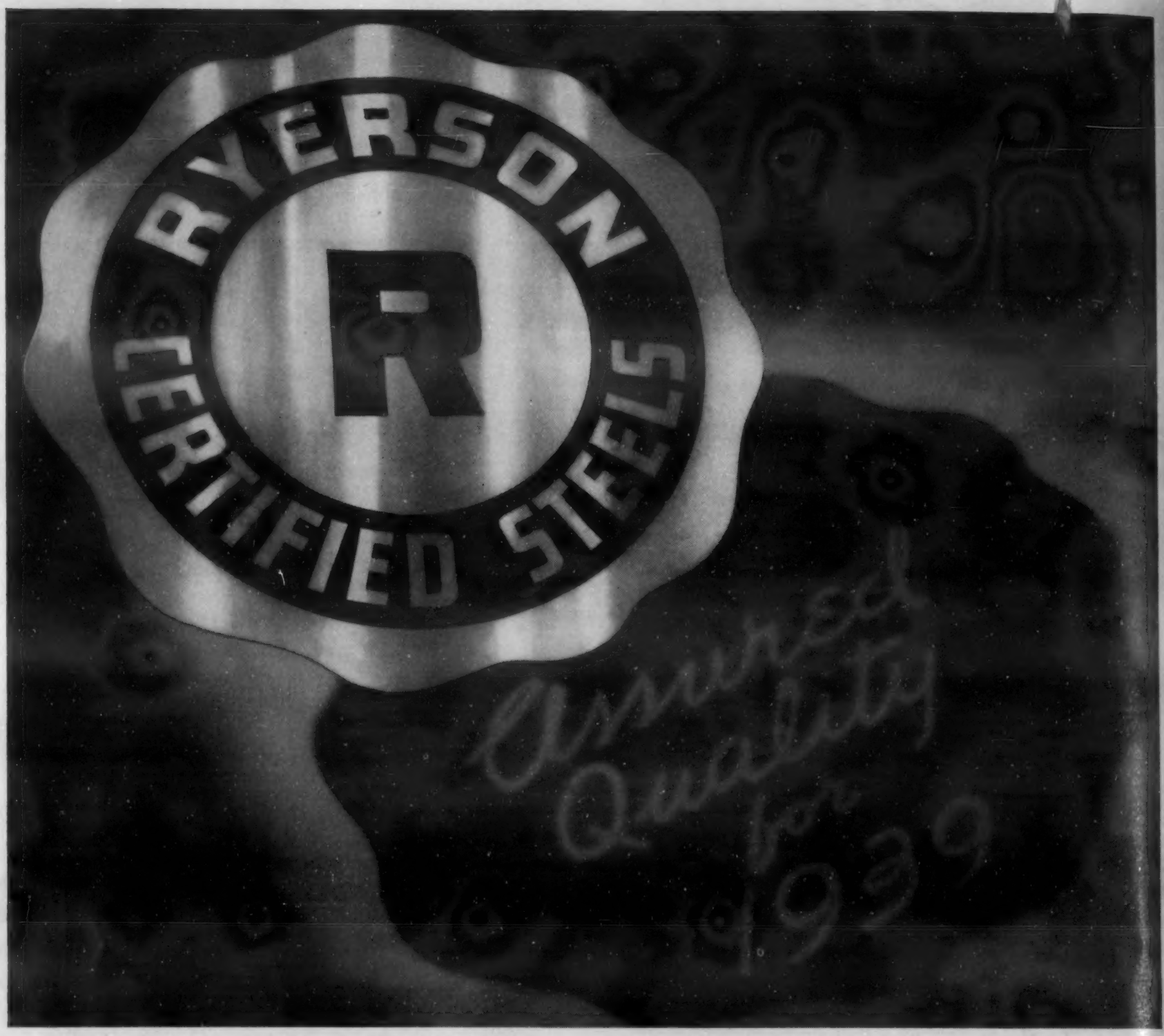
Glancing at the periodic table that hangs on the wall above our desk we note that the questionable elements lie on, or jut into, the border between the definite non-metals and the definite metals. Leaving out those that everyone will accept as metals we have the following:



Although some authorities speculate upon the metallic characteristics of H, that's certainly straining a point and in a spiral presentation of the periodic system, H isn't so much out on a limb as it looks in this.

This matter of location might point to something in the make-up of these elements that both gives them their position in the table and makes them non-

(Continued on page 32)



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RYERSON STEEL-SERVICE

by A. H. WOOLLEN

Railway Engineer, Development Division, Aluminum Co. of America, Pittsburgh.

Aluminum Alloys in the Railroad Industry

This article is a fitting supplement to others dealing with aluminum and its alloys which have been published in METALS AND ALLOYS. *In the October, 1935 issue, page 284, F. M. Howell and D. A. Paul discussed "Properties of Wrought Aluminum Alloys at Elevated Temperatures" and in the February, 1936 issue, page 29, E. H. Dix and J. J. Bowman contributed "Fifty Years of Aluminum Alloy Development." Last year H. D. McKinnon discussed "Aluminum in Marine Construction" in the July issue, page 157. In the present article we have a discussion of the application of aluminum and its alloys to the railroad industry, with particular reference to the present tendency of reducing the weight of equipment and thus increasing the payload.—The Editors*

ALUMINUM, LIKE ITS COMPANION METALS both ferrous and non-ferrous, can definitely attribute its ever-expanding list of modern commercial uses to the many fruitful research activities in aluminum metallurgy and the related investigations that have been carried on. The inherent properties of light weight, high resistance to the corrosive action of the atmosphere and a great variety of chemical compounds, high thermal and electrical conductivity, high reflectivity for radiant energy, and ease of fabrication, of course, originally opened the door to great possibilities for aluminum as an industrial metal. However, it remained for man to supplement these natural characteristics with higher mechanical properties and bring about commercial economy of production and use before aluminum could truthfully be called a material of industry.

The Aluminum Research Laboratories at New Kensington, Pa., are the Proving Ground for Many Aluminum Alloys Used in the Railroad Industry. Here a built-up structural test column of aluminum alloys is undergoing a laboratory compression test.

Aluminum, Metal of Modern Trains, "Comes to Life" in Silvery Molten Liquid Form in Electrolytic Cells, and is Drawn off and Cast into Pigs.

In These Huge Mills, Aluminum Alloy Plates for the Construction of Modern Lightweight Trains are Rolled.

Transportation Industry Largest Consumer

The transportation industry consumes, by far, the largest percentage of the aluminum produced in this country. A logical explanation for this lies in the theory of the mass and energy principle as applied to vehicles in which the energy that must be applied to give it a certain velocity is a direct function of its mass. It follows that the use of a light-weight material such as aluminum permits a significant reduction in weight and a consequent decrease in energy (motive power) for the same velocity or a greater velocity for the same energy applied. The use of aluminum in the railroads and street railways is an outstanding example of how the transportation industry has capitalized on the advantages of light-weight construction.

Strength and Durability Essential

Though lightness is an important factor in rail vehicles, light weight alone is not enough. Strength, durability, and economy of maintenance and use are also prerequisites that

any material must possess before it can be considered for extensive applications in the railroad field. Through the development of alloying and heat-treating practices and cold and hot working techniques, modern aluminum alloys have been made available in shapes and forms that have this desired strength, light weight, and economy. Tensile strengths that are comparable to those of structural steel are now available as a result of these developments.

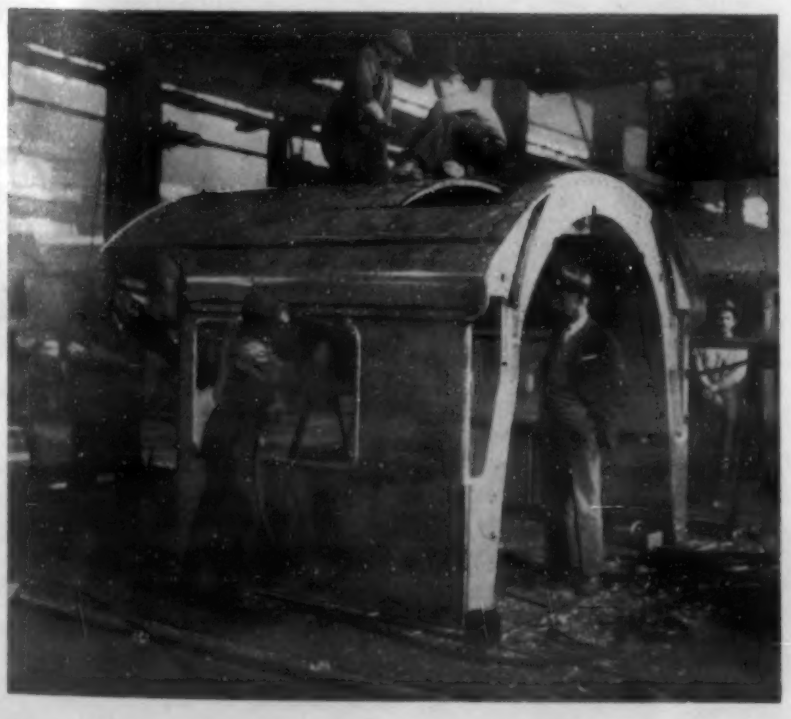
Nor was the factor of economy neglected in this search for a stronger aluminum. Countless improvements in the methods of manufacture of aluminum alloys has put them on a comparable long-run cost basis with other commonly-used materials for railroad construction.

The persistent desire to reduce operating and maintenance costs in railroads through the change from one material to another dates as far back as the origin of the railroads themselves. As might be surmised, the modern railroad is the outgrowth of the horse-drawn wagon, a means used for hauling coal and minerals from the mines of Great Britain during the seventeenth century. The roads traveled were, naturally, in a constant state of disrepair, and it was extremely difficult for the horses to pull the heavily-laden wagons, especially in wet weather.

The desire to overcome this difficulty and to haul greater loads led to the development of "wagon ways." The wagon ways merely consisted of wooden planks laid over the ruts in the road thus providing a hard surface for the wheels. Since the wagons frequently displaced the loose planks, it became necessary to introduce sleepers, or cross ties, to hold these "rails" in position. Although this innovation facilitated transportation considerably, it was found that the planks were subjected to an excessive wear that necessitated their frequent replacement. To offset this, metal strips, usually of iron, were attached to the top surface of the planks; but this, in turn, caused the wheels to wear out rapidly. The obvious solution to this problem was, of course, the substituton of iron wheels for the less durable wooden ones.

And so it has been right down through the developments that have given us our present-day streamlined high-speed trains. Materials of all types have been employed, experimented with, physically combined with and replaced by other materials. Today, research efforts are constantly being directed towards the still more efficient

Workers Riveting the Aluminum Alloy Cabs for the New York Central Railroad Locomotives.



Aluminum's Excellent Workability Makes it Well Adapted to the Hydraulic Extrusion Process. Through this method many complicated sections can be produced which reduce the number of forming, joining and fitting operations necessary in the actual construction of railroad rolling stock.

use of aluminum alloys so that they shall be employed only where they accomplish the best results possible and with the greatest economy.

Aluminum in Rolling Stock in 1894

Aluminum has not enjoyed the centuries of commercial existence that some of its competitive metals such as iron and steel have experienced. It remained for the introduction, but some 50 years ago, of the electrolytic process for its reduction to give it its first opportunity in the field of commercial metals. With this in mind, it is surprising to find that aluminum was used in the construction of light-weight rolling stock in 1894, a mere eight years after the present means for the reduction of aluminum was discovered. In this year, the New York, New Haven & Hartford railroad built a car of special light-weight construction in which aluminum seat frames were used. Other early applications of the metal found their way into the railroads, but most of these uses were comparatively small and of an experimental nature.

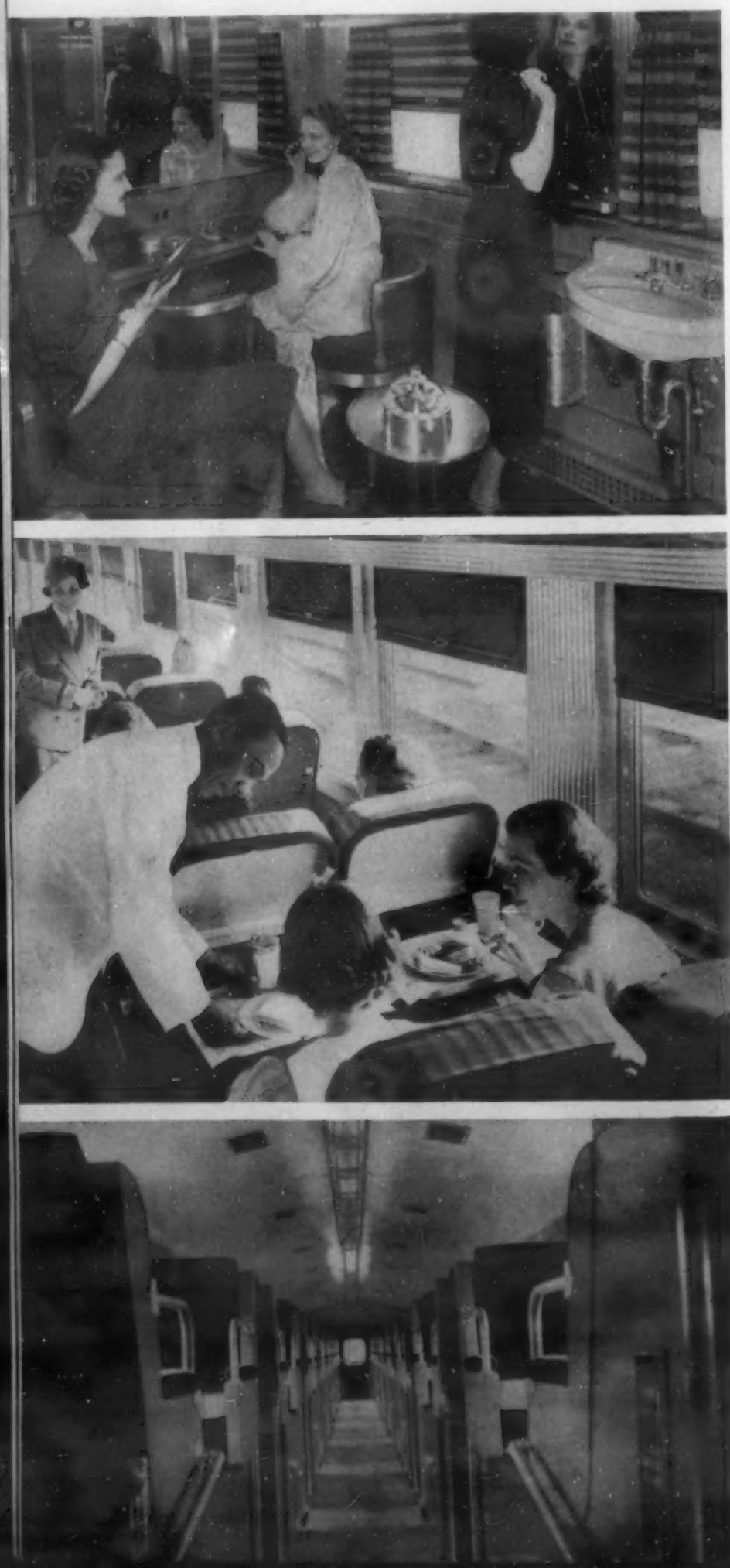
First Aluminum Suburban Cars in 1923

The first organized effort to lighten rolling stock through the use of aluminum came in 1923, when the Illinois Central System built 25 suburban cars with aluminum applications. As the advantages of the metal in these applications began to assert themselves, the use of aluminum increased steadily until, today, there are more than 2,500 railroad and street railway cars and locomotives that have been aluminized.

The physical properties of the wrought alloys are particularly well adapted to railroad car construction. Ultimate tensile strengths of the strong alloy used in railroad rolling stock construction range from 40,000 to 60,000 lbs. per sq. in., depending, of course, on the individual temper of the alloy. The wrought alloys have an average weight of about 1/10 lb. per cu. in. Since high tensile strength values are obtainable for correspondingly low weights, it is logical that these alloys are well suited for strength members as well as for sections subjected to low-stress to which aluminum was originally restricted. The lighter aluminum makes possible the use of thicker sections without exceeding weight limitations thereby affording high compressive strength, resistance to buckling, and resistance to localized loading. In addition, this practice often eliminates the need for corrugating and other extra forming that may increase construction costs.

The modulus of elasticity is practically the same for all the strong alloys and has an average value of approximately 10,300,000 lbs. per sq. in.

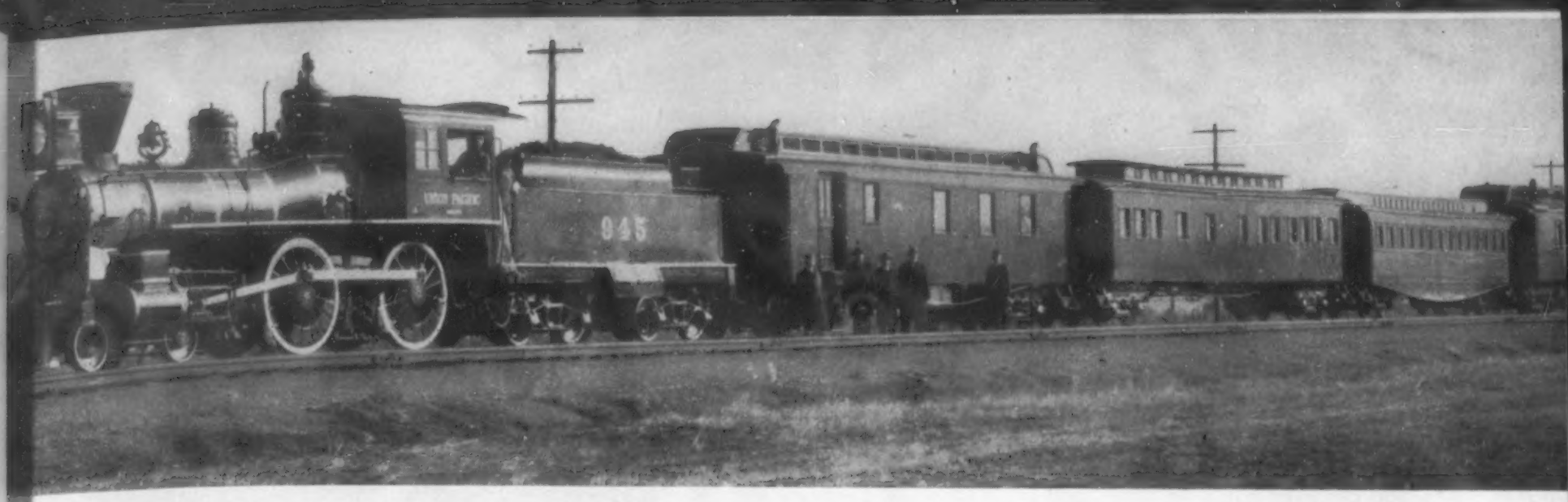
Because of the lower value of this constant as compared with that of steel, deeper sections in aluminum alloys are used to maintain the required deflection characteristics. Such redesign can be accomplished to produce a structure having the same deflection under load and actually higher ultimate tensile strength than would be obtained with



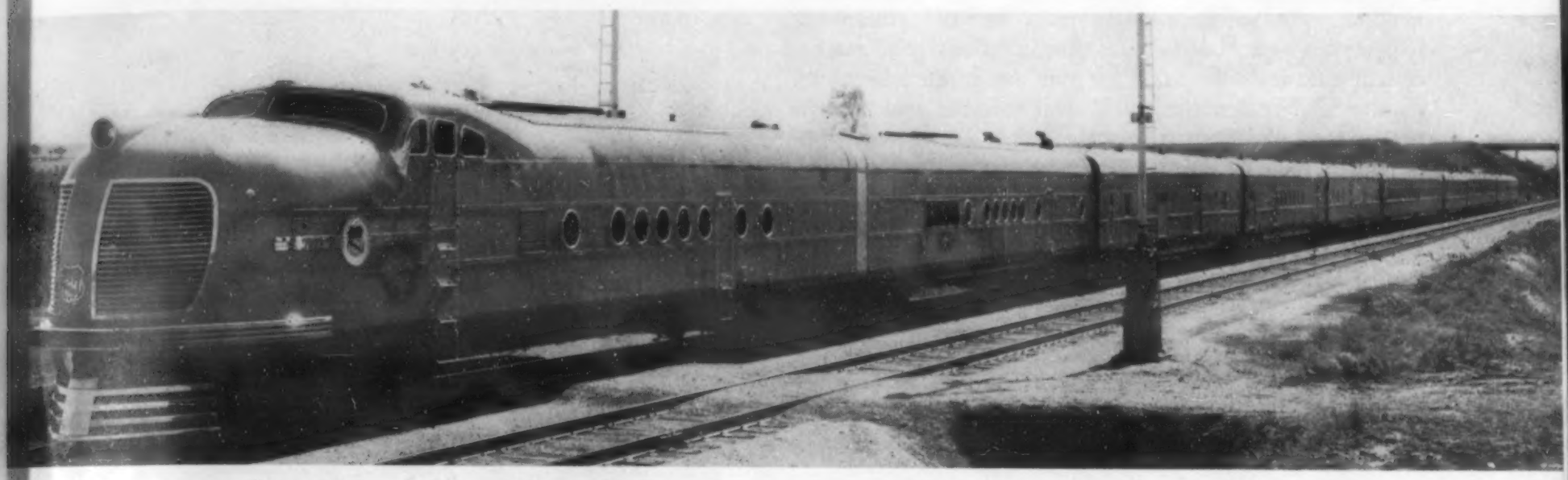
Alumilited Aluminum Alloy Trim (Top) are in Pleasing Prominence in the Ladies' Dressing Rooms on the New Union Pacific Streamliners.

Union Pacific's Streamliner, "City of Denver", has Luxuriously Fitted Coaches. (Center) The interior trim, pier panels, continuous window header, and parcel racks are 53S-T5 aluminum alloy with the Alumilite finish.

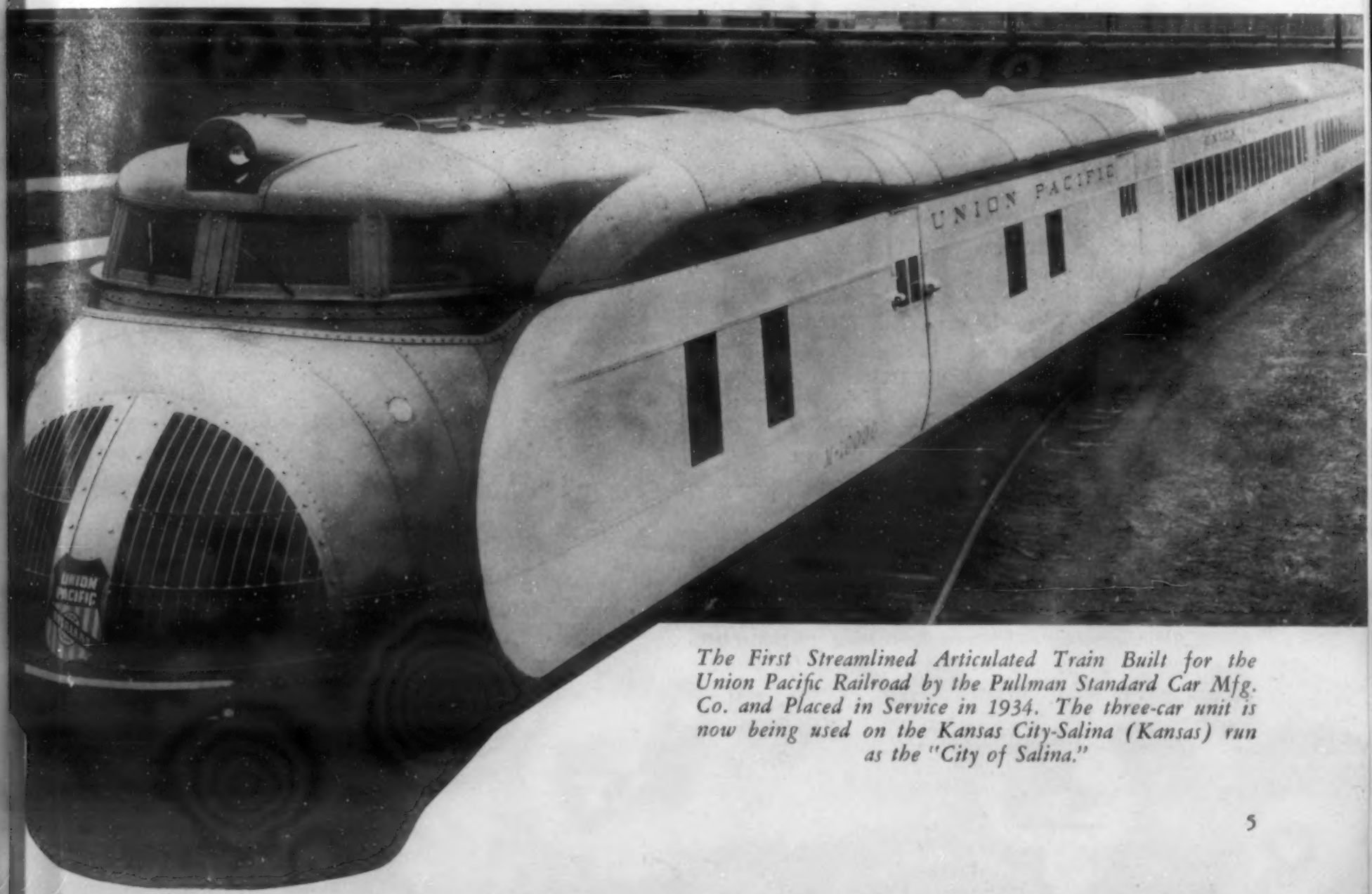
Interior View (Bottom) of the Long Island Railroad Double-deck All-aluminum Trailer Car.



Yesterday—An Old-time Union Pacific Train Composed of Rolling Stock in Use at Various Early Periods of Railroading.



Today—Union Pacific's Nine-car, All-aluminum "City of Denver" is a Majestic Contribution to Modern Railroading.



The First Streamlined Articulated Train Built for the Union Pacific Railroad by the Pullman Standard Car Mfg. Co. and Placed in Service in 1934. The three-car unit is now being used on the Kansas City-Salina (Kansas) run as the "City of Salina."

structural steel, and at the same time, to realize a saving in weight of more than a pound for each pound of aluminum alloy used. As a matter of fact, this lower modulus of elasticity is really an asset when impact loads are to be resisted, since other things being equal, the lower the modulus, the greater the ability to absorb energy without permanent set. Another advantage is the improvement of riding qualities of passenger cars.

Chemical Properties of Aluminum

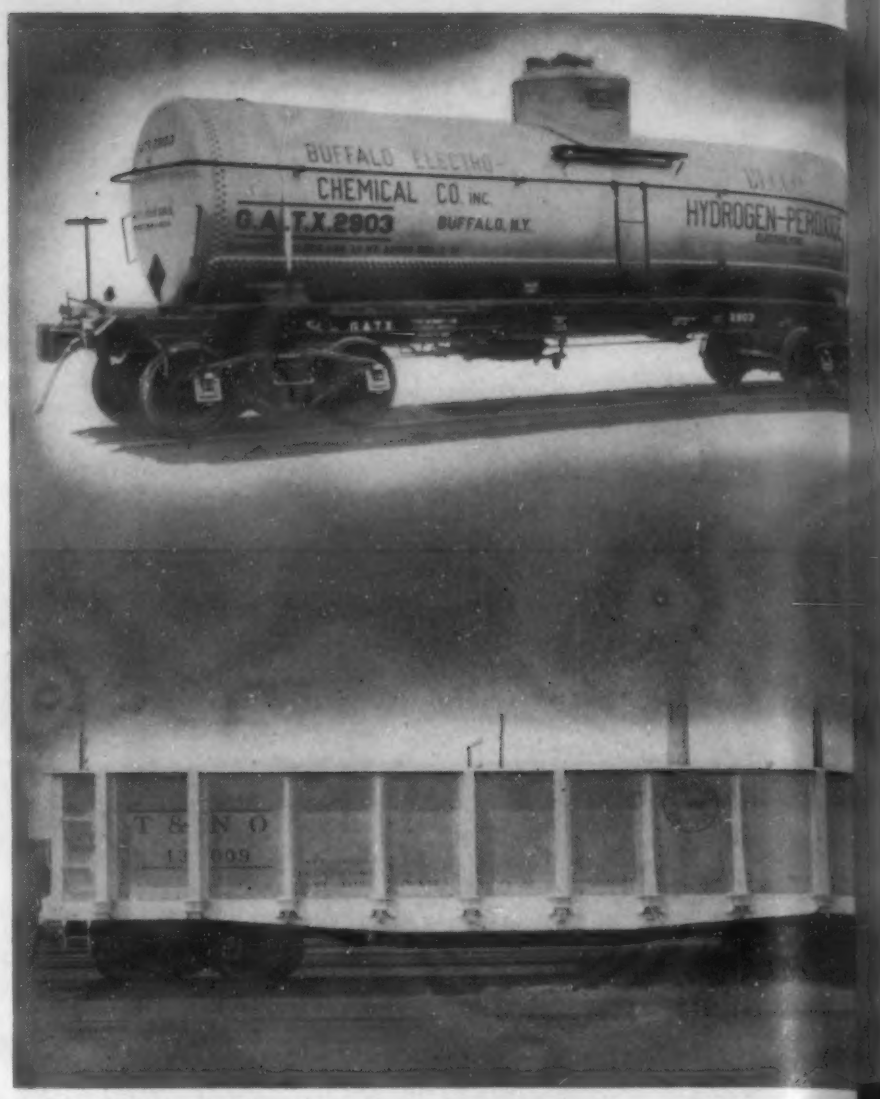
Aluminum's chemical properties cannot be neglected in a discussion of the metal as a railroad construction material. It possesses high resistance to atmospheric, and certain types of chemical attack. Food products and certain chemicals do not affect nor are affected by aluminum, which makes the metal a practicable selection for use in tank and hopper cars that come into contact with these types of products. Hydrogen peroxide, and acetic and nitric acids are common examples of liquid chemicals frequently transported in aluminum tank cars. It has been found that sulphur and sulphur-containing materials such as coal do not attack aluminum, and hopper cars of aluminum alloys have therefore been used experimentally for the transportation of these materials. Recently the use of aluminum tank cars for the transportation of aviation gasoline has been approved by the Interstate Commerce Commission.

Extruded Aluminum

An important advantage of aluminum is that it can be extruded in a variety of shapes and sections. Much labor in forming and assembly can be saved by using these extruded shapes which can be supplied in an almost unlimited number of cross-sections. Complicated assemblies can often be replaced by extruded sections. Through the variety of tempers made possible by heat treating, annealing, and subsequent working procedures, forming operations are greatly facilitated.

Joining practices in railroad car construction are governed principally by requirements of the finished joint as well as by the economy of the method selected. Although practically all the wrought alloys can be satisfactorily joined by the conventional riveting methods and fusion, arc, and resistance welding, riveting is used almost exclusively in the construction of the high stressed sections where the strong alloys are used. This practice preserves the characteristic mechanical properties of these alloys which depend upon carefully controlled heat treatment for these properties. For interior finish, welding can be used in order to give smoother and more decorative joints.

Practically any desired finish effect can be imparted to aluminum and its alloys, for electrolytic oxide, chemical dip, plated, mechanical, and paint and lacquer finishes are commonly employed for exterior applications of aluminum, while Alumilite (electrolytic oxide coating process; patented) processed material is used extensively for interior decorative trim and hardware.



A 70-ton Gondola Car for the Transportation of Raw Sulphur Built by the American Car & Foundry Co. for the Southern Pacific Railroad. Aluminum plates were used for sides, ends and bottom to replace wood planking formerly used, effecting a saving of weight of about 6500 pounds and promoting greater durability and corrosion resistance.

High Resistance to Chemical Corrosion Has Made Aluminum Alloys a Popular Choice for Tank Car Construction in Which Chemicals are Transported. This car, constructed by the General American Tank Car Corp. is employed for the hauling of hydrogen peroxide.

Duralumin

Although a variety of aluminum alloys have been found suitable for railroad rolling stock applications, extensive investigations in this direction and actual service data have brought about more or less of a standardization of the alloys employed in this manner. For example, the duralumin type alloy, designated as 17S by the Aluminum Co. of America, has found considerable use in the highly-stressed underframe sections of modern aluminum railroad cars. It is generally used in the heat-treated temper (17S-T) in rolled shapes or plate. The ultimate tensile strength of 17S-T is 60,000 lbs. per sq. in., a value comparable with that for structural steel.

Likewise, A17S-T, a modification of this duralumin type alloy, has been used to meet underframe design require-

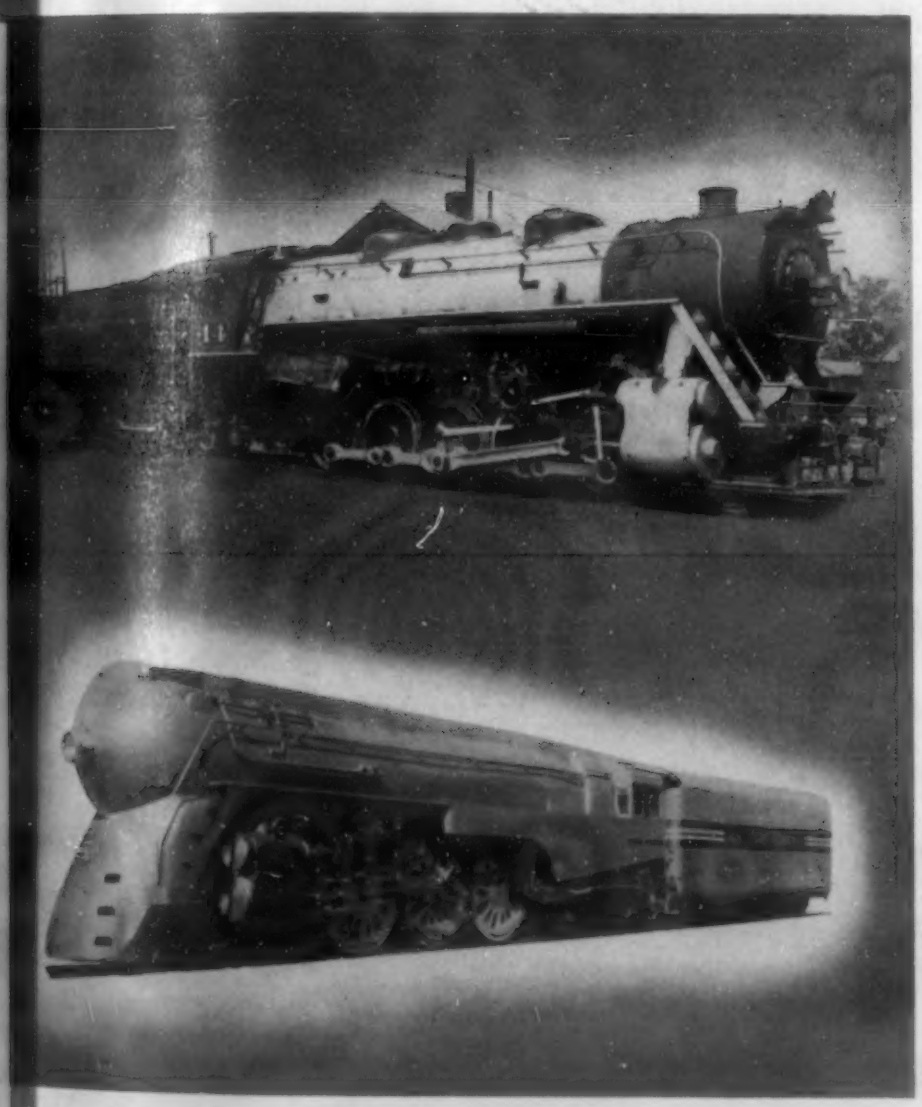
ments on some railroad cars. The properties of this alloy are somewhat lower than those of 17S-T, but its better cold working characteristics often dictate its use when the higher mechanical properties of 17S-T are not required in application. Posts, carlines, purlines, and other framing applications are examples of some of the standard uses for A17S-T structural shapes and sections, although some car designers specify use of 17S-T for these parts.

An Al-Mg-Si-Cr Alloy (53S)

An aluminum alloy that has been used in a large measure for side sheets is the aluminum-magnesium-silicon-chromium alloy, 53S, employed in the heat-treated, or "T," condition. Although 53S-T has lower mechanical properties than the more widely used 17S-T, it has the advantage of higher resistance to atmospheric attack for those applications where this characteristic is of prime importance such as coal hopper car framing shapes exposed to lading.

Forged Aluminum Alloy Side Rods for Alton & Southern Railroad Locomotives Exemplifies how the Light Metal can be Effectively Used for Locomotive Reciprocating Parts.

New York Central's Highly Aluminized Locomotives Used on the Twentieth Century Limited Service have Aluminum Cabs, Gage Boards, Running Boards, Headlight Cases, Cylinder Cases, Handrails, Cab Door Frames, Ornamental Nose Castings, and Crosshead Slippers.



Extruded sections in the modified heat-treated temper (53S-T5) have found wide application for interior trim.

The alloy 3S and commercially pure aluminum, 2S, are known as the common alloys in contrast with the strong alloys which have considerably higher mechanical properties. These common alloys are used extensively for unstressed and low-stress applications, such as decorative trim, because of their excellent working characteristics, economy, and corrosion resistance.

The Alloy 4S—An Al-Mn-Mg Alloy

An aluminum-manganese-magnesium alloy, (4S), is used extensively for roof sheets. This alloy is usually supplied in tempers adaptable to the subsequent cold forming requirements to allow for the strain-hardening that takes place when cold worked. The 4S alloy has substantially the same corrosion resistance as commercially pure aluminum under the same conditions of exposure.

Though the use of aluminum alloys in passenger trains today is the most outstanding example of the part they play in light-weight railroad construction, it, by no means, covers all the applications in the railroad field. In 1926, the Alton & Southern Railroad installed forged aluminum side rods on one of its locomotives. Since then practically all its locomotives have been equipped with aluminum alloy rods, and other roads are experimenting with their use.

Aluminum Alloy Cabs

Three railroad concerns have adopted aluminum alloy cabs for keeping the total weights of their locomotives within practical operating limits. The latest road to use aluminum cabs is the New York Central which has recently placed in service 40 such motive power units. The New York Central's Twentieth Century Ltd. locomotives have been highly aluminized with ornamental nose castings, running boards, headlight cases, cylinder casings, gage boards, hand-rails, emblem plates, cab door frames, and cross-head slippers.

The very fact that aluminum first enjoyed widespread popularity as a metal from which kitchen utensils were made and has since made remarkable strides to become one of the world's most important industrial materials is dependable evidence that its future in the railroads is, to say the least, promising.

The already impressive list of forms in which aluminum alloys are produced is not wholly the result of industry's demands, and considerable credit must be given to the farseeing investigating that has been carried on since the metal's industrial possibilities were first realized. These conditions must exist simultaneously in order to effect the most productive results. Neither can exist for any length of time independently, and the correlation of needs of the railroads and the developments in aluminum alloys have accounted for the truly amazing progress in railroad construction that has given America the greatest rail system in the world.

Silicon Carbide Additions to Cast Iron

by JOHN A. BOYER

Research Dept. The Carborundum Co., Niagara Falls, N. Y.

The problem of additions to cast iron, when they should be made, and their nature, is of perennial interest to foundrymen. The author presents the thesis that the addition of silicon and carbon in the form of silicon carbide accomplishes certain results which are not duplicated by ordinary silicon and carbon additions. Before fully accepting this thesis, metallurgical engineers will await information on comparative tests, planned to establish definitely whether silicon carbide additions do have a different effect than ordinary silicon or carbon additions.

Regardless of its mechanism, it is of decided interest to have this account showing that silicon and carbon can be utilized as silicon carbide.

The etching technique, and the evidence that the "phosphide eutectic" is a complex, rather than a definite entity, and hence is susceptible to alteration by adjustment of composition, are not the least interesting parts of the article. The data on the phosphide eutectic correlate nicely with those previously presented by M. Kunkule. Mitt. Kaiser-Wilh. Inst. Eisenf., Vol. 12, 1930, pages 23-31.—H.W.G.

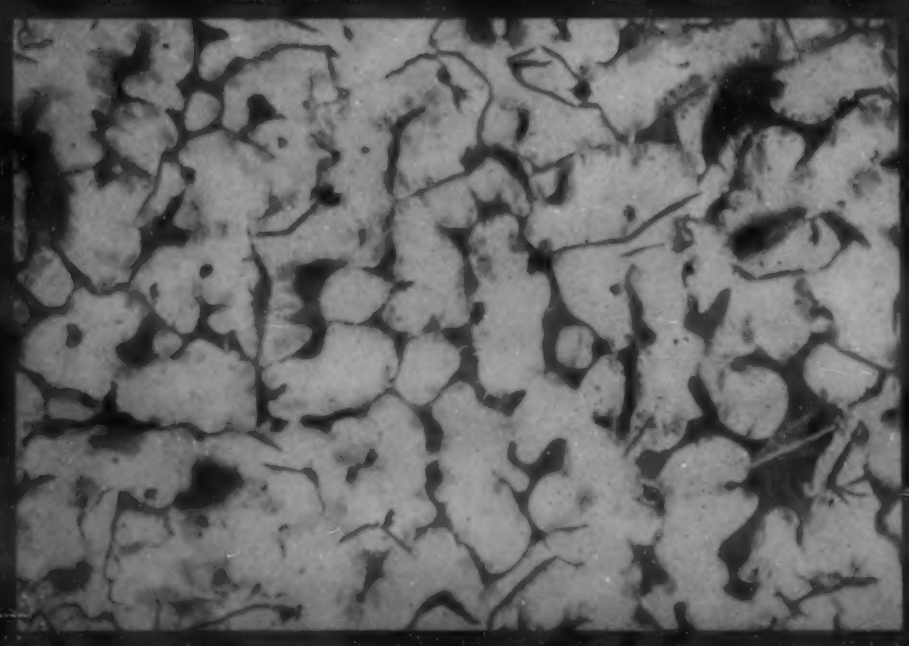
A CAREFUL SURVEY OF THE LITERATURE of cast iron reveals surprisingly little metallographic work on the changes that take place in the iron during solidification and cooling. The purpose of the present investigation was to study the changes in microstructure produced by the addition of silicon carbide to cast iron, for it had been found experimentally by Brown[1] that silicon carbide additions had a marked effect upon the graphitic structure and the physical properties of the treated iron. So little satisfactory information was available regarding the mechanism of graphitization and the changes produced in the hard constituents during cooling, that it seemed necessary to include a study of these phenomena in order to interpret the changes produced by the addition of silicon carbide.

General Effects of SiC Additions

With irons low in phosphorus, a charge that would normally result in a white iron can be treated with about 1 per cent silicon carbide to produce a machinable gray iron having a tensile strength in excess of 40,000 lbs. per square in. With an iron having an intermediate phosphorus content, the phosphide complexes, which ordinarily cause hard spots or render an iron made from a high scrap charge difficultly machinable, are broken up without an

Fig. 1. Phosphide-Carbide Network in Iron. Made by Re-melting 100 per cent Stove Plate Scrap. Alkaline sodium picrate etch. Si—1.19, Mn—0.26, P—0.58, S—0.108, T. C.—3.18 per cent. 100 X.

Fig. 2. Iron Made from Same Charge as Fig. 1, but Treated with Silicon Carbide. Si—1.50, Mn—0.31, P—0.61, S—0.108, T. C.—3.30 per cent. 100 X.



appreciable coarsening of the graphitic structure. With a high-phosphorus iron, the phosphide eutectic tends to form a continuous cellular network which is usually broken up by a high carbon, a high silicon and a low sulphur content; with silicon carbide additions, a harder charge can be used and more satisfactory physical properties obtained without decreasing machinability.

In adding silicon carbide, one would naturally expect some softening action owing to the silicon (and possibly the small amount of carbon) which dissolves in the iron. The silicon carbide, however, is usually added in quantities of 1 per cent or less, and the effects produced, in the author's opinion, cannot be accounted for by the silicon or carbon "pick up". If granular silicon carbide is added to a ladle of molten iron, a vigorous exothermic reaction takes place, which presumably results from the decomposition of the silicon carbide and the alloying of the nascent silicon and carbon with the iron. In adding silicon carbide to the cupola, temperature increases of some 75 to 150 deg. F. have been observed, as compared with usual operation. Most of the silicon is consumed during this reaction, especially when the charge is high in scrap, and there is apparently a vigorous scavenging or deoxidizing action. Such a reaction is not produced by ferro-silicon, for the silicon is already alloyed with the iron before it is introduced into the charge.

Regardless of the mechanism of the reaction between the silicon carbide and the iron, tests over a period of several years have shown improved physical properties, better machinability and certain desirable changes in microstructure over corresponding untreated irons made from higher percentages of pig.

Machinability and Hard Spots

The machinability of cast iron involves so many variables that it is difficult to correlate this property with microstructure. The ease in machining depends to such an extent upon production rate required, the type of tool used, the time during which the tool will retain its sharpness, and the speed and depth of cut, that an iron which may be regarded as having fairly satisfactory machining properties in one foundry may be regarded as unsatisfactory in another. In connection with the present investigation, samples were available from many large foundries, in which the machinability was reported as very good or exceptional; other specimens were submitted in which the machinability was reported as being poor. In the poorly machinable specimens, the so-called "hard spots" were usually encountered.

It is a common impression that hard spots in gray iron are caused by undecomposed cementite or massive carbide. Metallographic examination showed that in an unalloyed gray iron having a medium phosphorus content, iron carbide itself is not the cause of hard spots, even in a poorly machinable iron. The hard spots in most gray iron castings consist of phosphide or phosphide-carbide complexes. A typical micrograph of such an area is shown in Fig. 1. It is only in the low phosphorus irons that the hard spots are due to undecomposed cementite.

The distribution of hard constituents with respect to the graphitic structure, and not the total quantity of hard constituents, is the chief criterion of machinability. Repeated tests have shown that microscopic particles of phosphide or carbide do not render the iron difficultly machinable if these constituents are interspersed with or broken up by graphite flakes. The problem is to break up the hard network of constituents with the minimum amount of softening and graphite growth. In typical hard spots, the network is continuous over a volume which is macroscopic rather than microscopic; the cutting tool has to break through these continuous cells of hard constituents to reach the more ductile portions of the metal, and these hard spots have about the same machinability as a white iron. If they become appreciable in size or more or less continuous throughout the metal, machining becomes difficult or impossible.

As previously pointed out, there are two types of iron commonly encountered in gray iron castings. In one type of iron, illustrated in Fig. 2, there is a coarse network of

Fig. 3. Typical Distribution of Hard Constituents. Made from a charge consisting of 100 per cent scrap, treated with silicon carbide. Si—1.98, Mn—0.40, P—0.57, S—0.141, T. C.—3.34 per cent. 50 X.

Fig. 4. Distribution of Hard Constituents in a 0.6 per cent P Iron, Made from a High Percentage of Pig. Deeply etched with Nital. Coarse network of hard constituents almost continuous throughout the iron. Si—1.95, Mn—0.59, P—0.65, S—0.093, T. C.—3.30 per cent. 50 X.

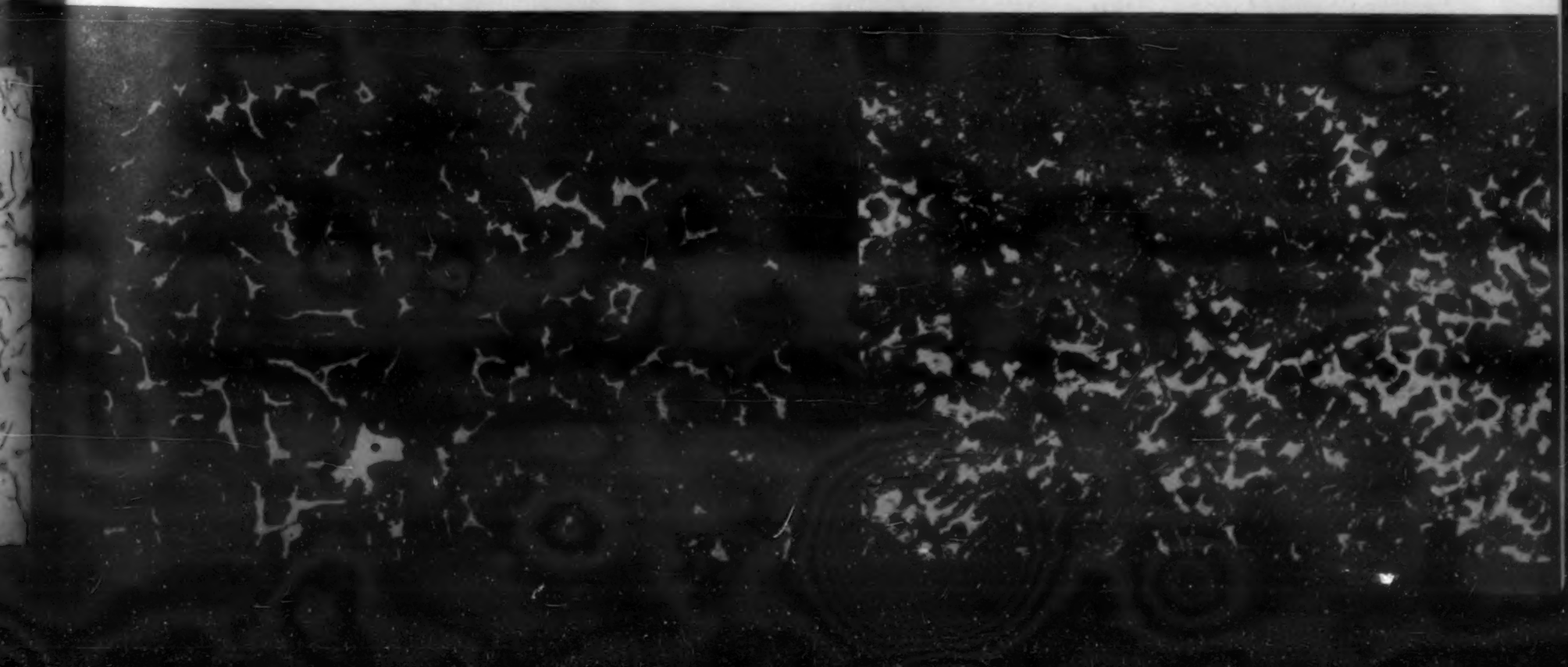


Fig. 5. Hard Constituents Forming a Cellular Network Around Areas of Pearlite, which were Originally the Lobes of the Primary Austenite Dendrites. Acid etch. Si—1.80, Mn—0.32, P—0.44, S—0.15, T.C.—3.13 per cent. 1000 X.

Fig. 6. Same as Fig. 5, but with the Carbide Etched with Alkaline Sodium Picrate. The carbide in the central portion of the micrograph occurs as long "needles". Si—1.80, Mn—0.32, P—0.44, S—0.15, T.C.—3.13 per cent. 1000 X.

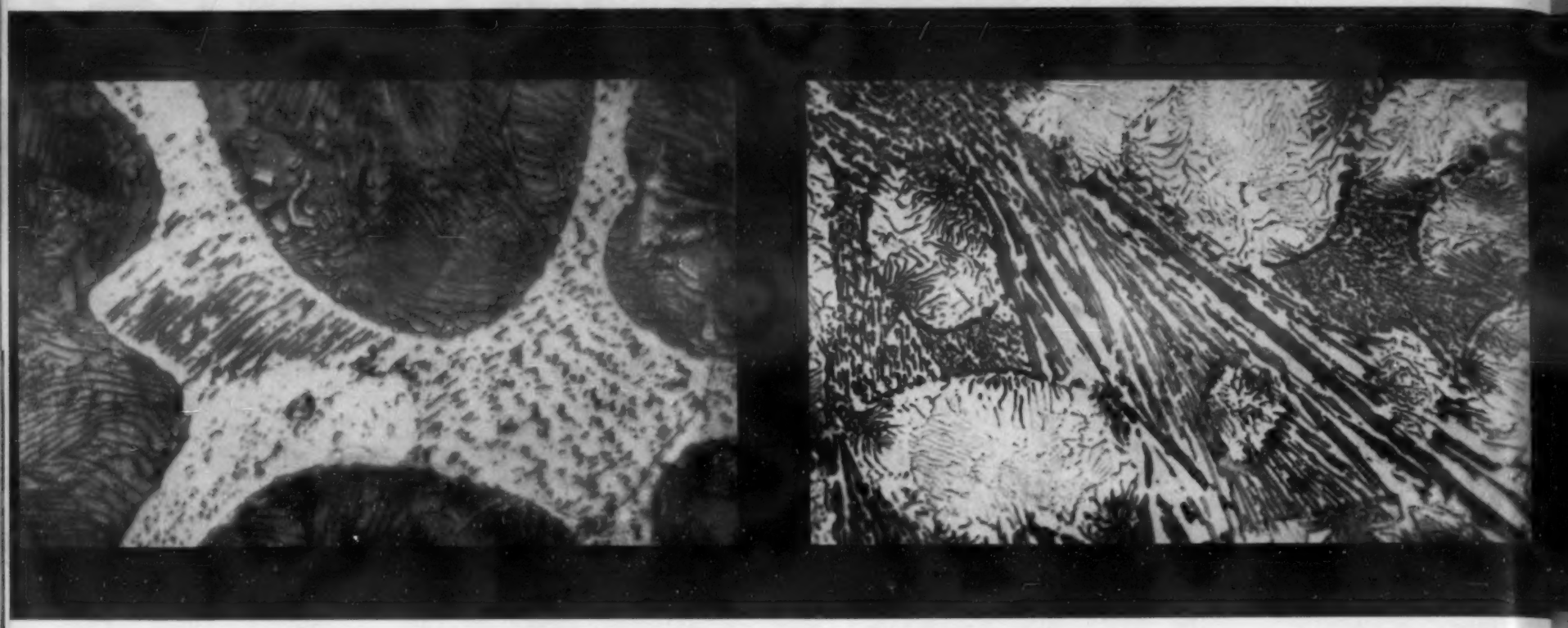


Fig. 9. Characteristic Crystals of Phosphide (White) in the Phosphide Eutectic of Gray Iron. Carbide etch, followed by etching with Nital. Carbide appears in half tone. Si —1.98, Mn—0.40, P—0.57, S—0.141, T. C.—3.34 per cent. 1000 X.

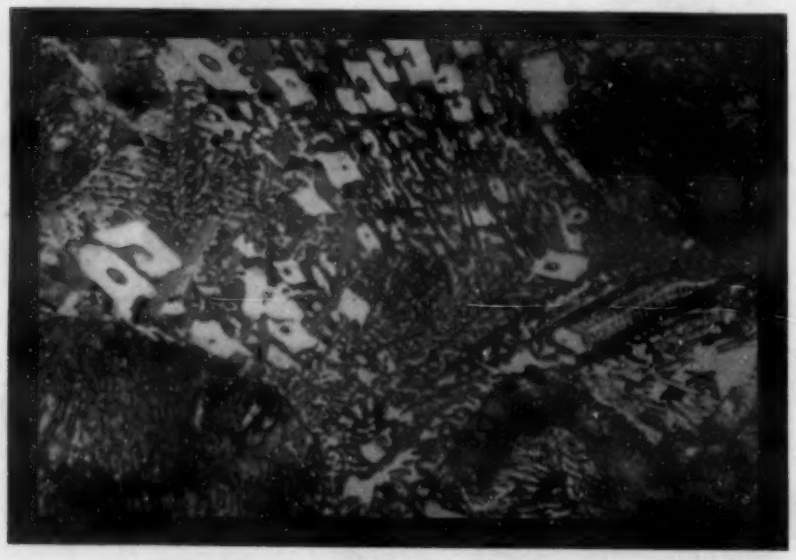
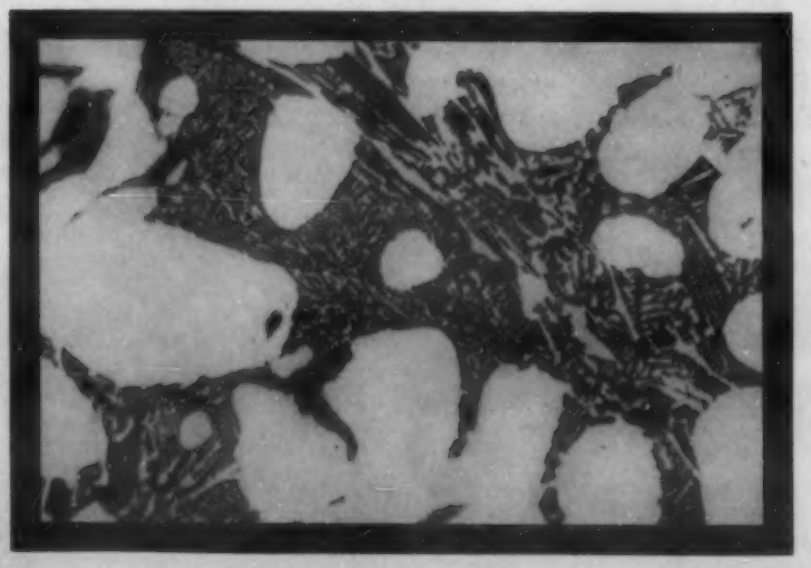


Fig. 10. Synthetic Iron—Phosphorus—Carbon Alloy Containing 4.13 per cent Carbon and 1.82 per cent Phosphorus. Phosphide dark. Alkaline ferricyanide etch. Si —0.84, Mn—0.74, P—1.82, S—0.232, T. C.—4.13 per cent. 500 X.



hard constituents surrounding large areas consisting of either pearlite or ferrite and graphite. Such an iron may or may not be machinable, depending upon whether the coarse network is continuous or is broken up by graphite. It is possible, however, to have a poorly machinable iron without the presence of isolated hard spots.

In irons which are devoid of the coarse network structure, the machinability depends primarily upon the presence or absence of large isolated areas in which the carbide-phosphide complexes surrounding the individual dendrites are continuous and are not interspersed with graphite flakes. The size and continuity of the graphite flakes, and even a cellular segregation within the pearlite itself (which has been shown in many instances both by etching and by scratch hardness tests) will, of course, have some effect upon machinability. In general, however, an iron having the structure shown in Fig. 2, in which the hard constituents are broken up and interspersed with fine graphite flakes, will be readily machinable even when the matrix is pearlitic.

A typical distribution of hard constituents in a silicon carbide treated iron made from a charge consisting entirely of a good grade of scrap, is shown in Fig. 3. Fig. 4 is a similar section of an untreated high phosphorus iron.

The Microstructure of Cast Iron

When silicon carbide was introduced commercially as an addition agent for cast iron, hundreds of specimens of all types of cast iron became available for metallographic examination. These specimens were for the most part cast under regular cupola melting conditions in large foundries; others were small scale tests, while a few of the samples were melted in the laboratory. The specimens ranged from iron made from 100 per cent stove plate scrap to high test iron, and from remelted malleable scrap to iron made from high-phosphorus pig. Step tests and telescopic castings were also available from many of

Fig. 7. Phosphide Eutectic in White Iron. Carbide dark, phosphide half-tone. Iron particles in the eutectic appear white. Alkaline sodium picrate etch. Si—0.87, Mn—0.27, P—0.57, S—0.112, T. C.—2.96 per cent. 1000 X.

Fig. 8. The Same Area as in Fig. 9, but with the Etch Reversed. Phosphide dark, carbide faintly etched; graphite flake beginning to break through the eutectic. Si—0.87, Mn—0.27, P—0.57, S—0.112, T.C.—2.96 per cent. 1000 X

the heats. As the specimens covered almost the entire range of compositions used in ordinary gray iron, an opportunity was afforded for studying the microstructure of cast iron under widely varying conditions.

The following observations, while not entirely new, are believed to give a fairly clear picture of the changes in microstructure produced during graphitization:

1. Phosphorus is the controlling element which determines the extent to which the graphitization must be carried to make gray iron machinable. In a low-phosphorus iron, it is only necessary to graphitize the massive carbide or cementite; this can be done with a low carbon content, a relatively low silicon content, and with very little graphite growth.

2. When the phosphorus content is increased to a range of about 0.4 to 0.6 per cent, as is the case with most ordinary castings, the graphitization process must be carried further than that required to decompose the massive carbide. The cellular phosphide-carbide complexes also must be broken up by graphite.

3. In a machinable gray iron in this intermediate phosphide range, no massive carbide or cementite has ever been observed in the examination of several hundred specimens. (The terms "cementite" and "massive carbide" are used to distinguish iron carbide free from phosphide from the carbide contained in the phosphide eutectic or other phosphide complexes.) The presence of this constituent, as distinct from the carbide contained in the phosphide-carbide complexes, is almost certain evidence of lack of machinability.

4. The phosphide eutectic usually retains considerable carbide on cooling, but the quantity is highly variable. Even a soft iron may contain carbide in the phosphide-rich areas, whereas occasionally in a pearlitic iron the phosphide is relatively free from carbide. Sulphur appears to be the important factor in stabilizing the carbide in the phosphide-rich areas. In a high-sulphur iron (or an iron in which the ratio of sulphur to silicon is high) iron carbide may be present even in its characteristic primary form of long needles, which may be sections of plates. These "needles," of course, are not primary cementite, but are presumably formed during the crystallization of the phosphide eutectic.

5. In a gray iron of intermediate phosphorus content that cannot be satisfactorily machined, the original dendrites are surrounded partially by graphite and partially by the usual type of phosphide eutectic. In addition, a phosphide-carbide complex also is present that has a different appearance from the phosphide eutectic in either a machinable gray iron or a white iron.

6. Hard spots in a gray iron of medium phosphorus content are not caused by undecomposed cementite, as is often presumed, but usually consist of cellular areas of phosphide eutectic which are not broken up by graphite. Hard spots are macroscopic in character rather than microscopic, and include a large number of dendrite lobes. Isolated microscopic particles of hard constituents have little effect upon machinability, if they are sufficiently interspersed with graphite.

7. The addition of silicon carbide to a low phosphorus iron stabilizes the structure, makes possible the use of a harder charge with the production of very fine graphite, and minimizes the abrupt changes that take place in such a charge. In a charge containing a medium or high percentage of phosphorus, it breaks up the carbide-phosphide complexes, reduces the carbide content of these complexes, and causes graphite to break up the cellular structure of hard constituents to make the iron machinable.

Etching For Carbide and Phosphide

Cast iron is usually etched with acid solutions, which do not attack the hard constituents in the iron. These etches are necessary to determine the degree of softening

of the matrix. and in the present investigation all specimens were subjected to the usual etching treatment. It was found, however, that for some purposes the acid etches had a number of disadvantages. Machinability, for example, is closely related to the breaking up of the hard constituents in the iron, and as an acid etch does not distinguish between iron carbide and iron phosphide, it is impossible in a pearlitic iron to determine to what extent the iron carbide has been decomposed. The distribution of hard constituents in relation to the graphitic structure is also of importance, and with an acid etch at low magnification, the graphite often cannot be distinguished from the mottled mass of pearlite. Most of the present micrographs were selectively etched for carbide and phosphide, and are intended to give information to supplement that obtained with usual acid etches. In practically all cases the matrix was pearlitic, unless otherwise stated.

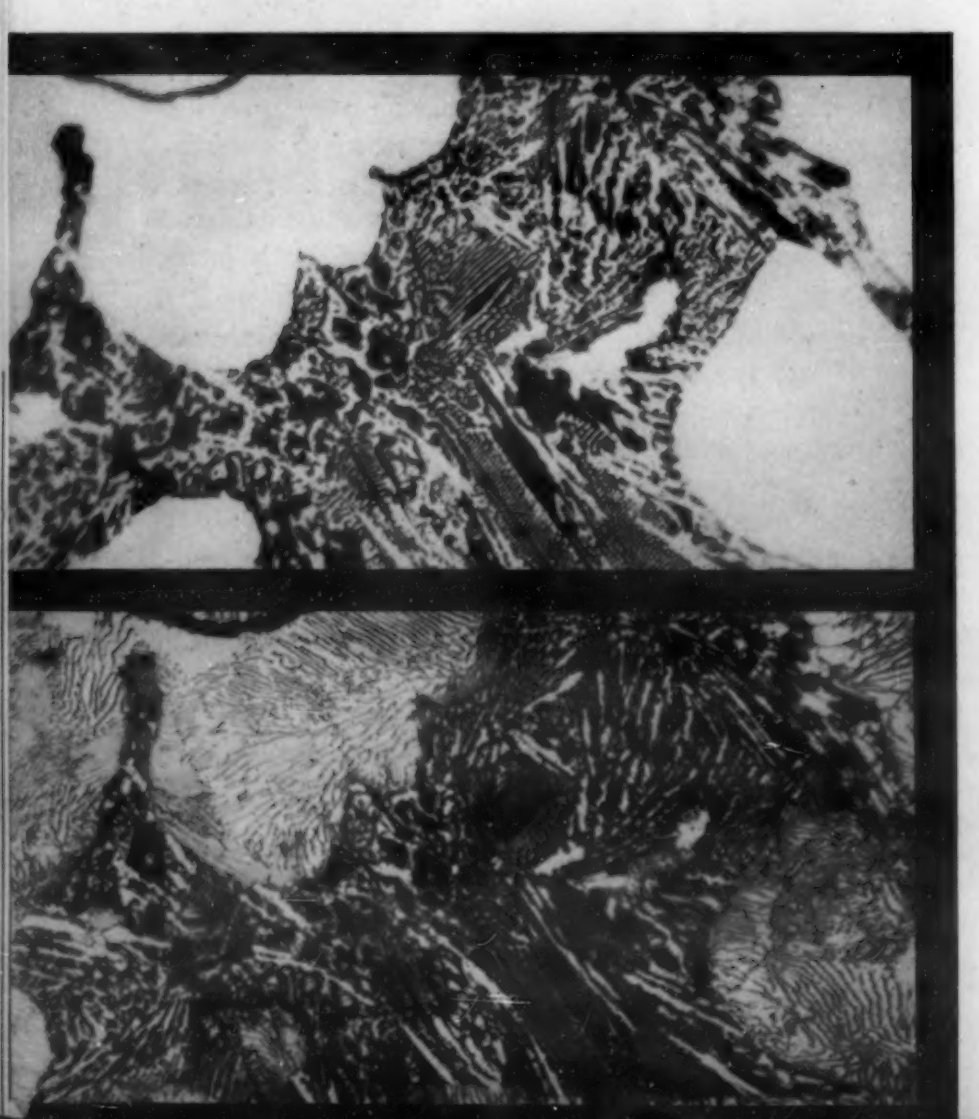
Le Chatelier[3] and Murakami[4] etches as described by E. L. Reed were tried, but were not found to be satisfactory, and it was also necessary to alter concentration and proportions of the ingredients for different types of cast iron. The alkaline sodium picrate attacks both the carbide and the phosphide, and the etch can even be reversed, as is shown in Figs. 7 and 8 so that some experience and care is needed in interpreting the etched microstructures.

It is not possible to go into detail regarding the etching procedures used in the present study but the following solutions are given as examples:

Etch for Carbide:

Sodium Hydroxide (pellets)	20 g.
Picric acid	0.35 g.
Water	250 cc.

Fig. 11. Phosphide Area in Low-Sulphur Pearlitic Iron having a Phosphorus Content of 0.6 per cent. Alkaline ferricyanide etch. 1000 X. Fig. 12 (bottom). Same Area as Fig. 11, but Re-etched with Nital. 100 X.



The picric acid is dissolved in 20-30 cc. of water, the solution heated to boiling, the caustic added carefully in small quantities, and the solution, which should be almost black, is diluted to 250 cc. The final etch should be a very dark red, and free from any precipitate. The specimen is boiled in the etch for 3 to 5 min.

Etch for both Carbide and Phosphide: Add 5 grams sodium citrate to the above solution. Decreasing the picric acid content and prolonged heating below the boiling temperature increase the attack on the phosphide, and if desired, the phosphide can be etched until it is black.

Specific Etch for Phosphide:

Sodium Hydroxide	15 g.
Potassium Ferricyanide	3 g.
Sodium Citrate	3 to 5 g.
Water	100 cc.

Etch for 30 sec. with a fresh solution at a temperature of 90 to 100 deg. F. A cold solution, or one not freshly made, will give an unsatisfactory etch.

Hard Constituents Present in Cast Iron

Fig. 5 shows a portion of a network of hard constituents surrounding pearlitic areas in a hard gray iron. These pearlitic areas were originally the lobes of the primary austenite dendrites. With acid etching, no structure is developed except the etching of the pearlite and of the iron particles in the hard network. The structure shown in Fig. 6 is obtained when the same specimen is etched for carbide. The particular specimen had a low total carbon, a low percentage of silicon, and a high percentage of sulphur.

Figs. 7 and 8 show the structure of the phosphide eutectic in a white iron, as etched under different conditions with alkaline sodium picrate. Fig. 8 shows the characteristic phosphide structure found in a hard iron.

Although iron carbide can crystallize in its primary form in the phosphide eutectic of a hard iron, as is indicated in Fig. 6, eutectic areas are often found in which euhedral crystals of iron phosphide are present. An area of this type is shown in Fig. 9, where the white crystals of phosphide are characteristic of primary iron phosphide as it occurs in high phosphorus alloys. In a soft iron, these characteristic phosphide crystals in somewhat distorted form are usually present in the residual phosphide eutectic, after the iron carbide has disappeared.

Fig. 10 shows the etching effect obtained with alkaline ferricyanide in treating the synthetic alloy containing about 2 per cent phosphorus. The alloy was very low in silicon and was almost a white iron, but the iron carbide remained unattacked.

Figs. 11 and 12 show the same area in a low sulphur pearlitic iron of medium phosphorus content. Fig. 11 was etched with alkaline ferricyanide alone, whereas Fig. 12 was first etched with alkaline ferricyanide and then etched with nital. The carbide particles in the phosphide area are unattacked in both cases.

(To be concluded)

This is another in our "advanced practice" series—articles published to provide metallurgical engineers in various industries with factual information concerning the latest methods for handling metals. Previous articles on carburizing have covered electric salt bath practice (August, 1938, page 183) and modern pack-hardening technique (October, 1938, page 255). No series on case hardening could be called complete that did not include a discussion of gas carburizing, and we have chosen in this instance to describe propane gas practice because it has been so seldom discussed in the metallurgical literature.—The Editors.

Gas Carburizing with Pure Propane

Case-hardening—or more specifically, carburizing—is one of the oldest, most useful and least standardized of the metallurgical arts. The well-informed metallurgical engineer today is entirely familiar with the commonly employed methods of carburizing, that is, he knows how each is carried out and has at least a rough idea as to the relative costs of, and the results obtained by, pack hardening, cyanide treatment and gas carburizing. But evaluation of their respective merits on a strictly comparative basis for a particular job is a problem that seldom yields to easy solution. The cost and quality factors, with all their sub-variables, must be carefully compared, balanced and counter-balanced, and fortunate indeed is he who, once having selected his material, process, procedure and equipment, has no subsequent twinges of doubt concerning his decision.

This article makes no attempt to prescribe a general formula for selecting the best carburizing method for a given job. The purpose is merely to describe a method that has been proved in actual practice and to put enough data from users' experience on the record so that the engineer wrestling with the "How will I carburize?" problem, may be able to make his decision with a little more assurance that, however he carburizes, it will be the "one best way" for his job.

Gas carburizing itself is not new, but its wide industrial application is. The potential advantages of gas carburizing as commercial practice have long been known, but the present successful and widespread utilization by industry resulted directly from the development and perfecting of container or retort materials that were non-porous, resistant to high temperatures and practical from the production

by FRED P. PETERS and M. G. FARRAR

Assistant Editor, Metals and Alloys, and Engineer, "Pyrofax" Gas Div., Carbide and Carbon Chemicals Corp., New York, Respectively

Fig. 1. "Pyrofax" Gas Carburizing Furnace in Operation.

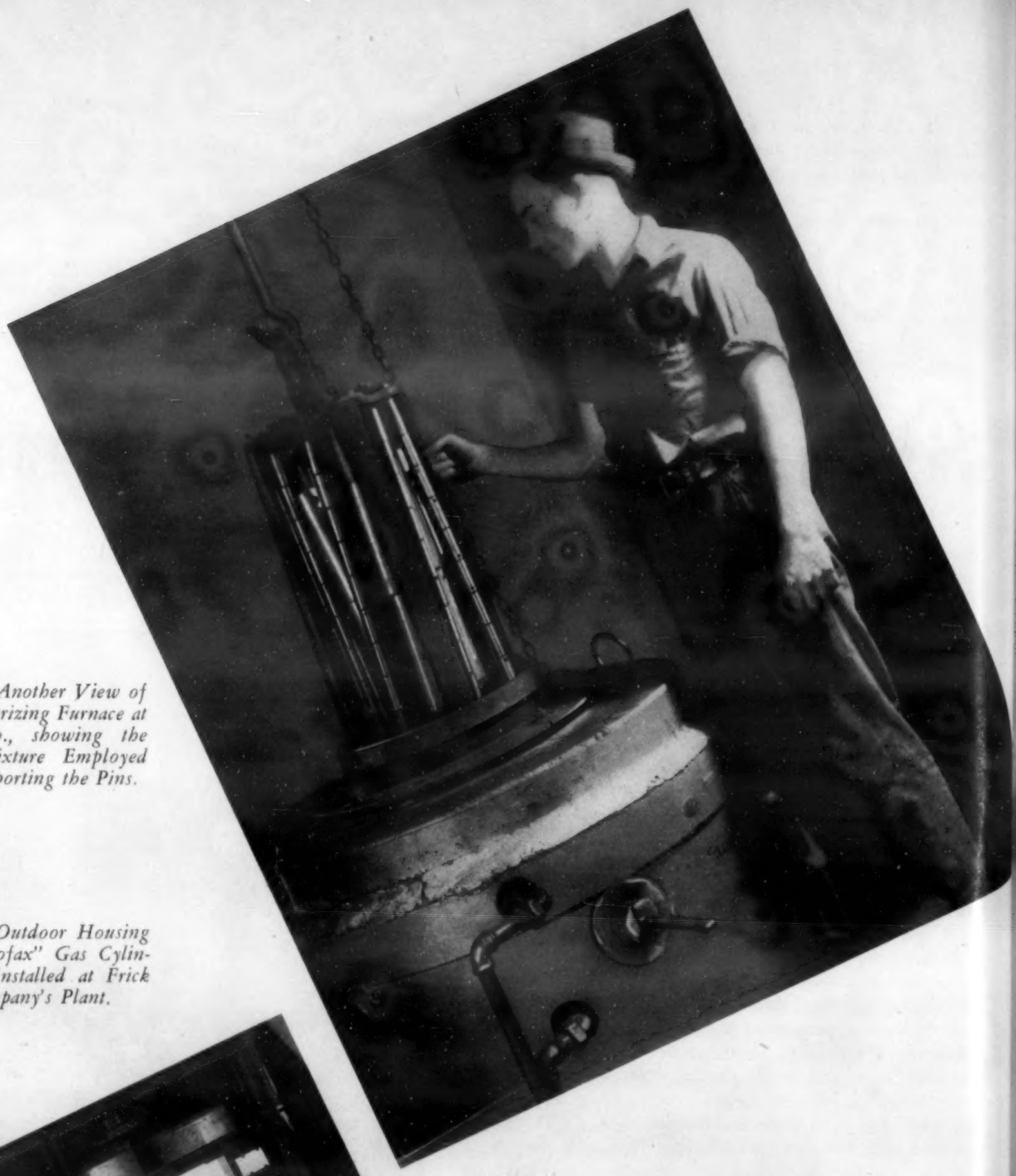


Fig. 2. Another View of the Carburizing Furnace at Frick Co., showing the Work Fixture Employed for Supporting the Pins.

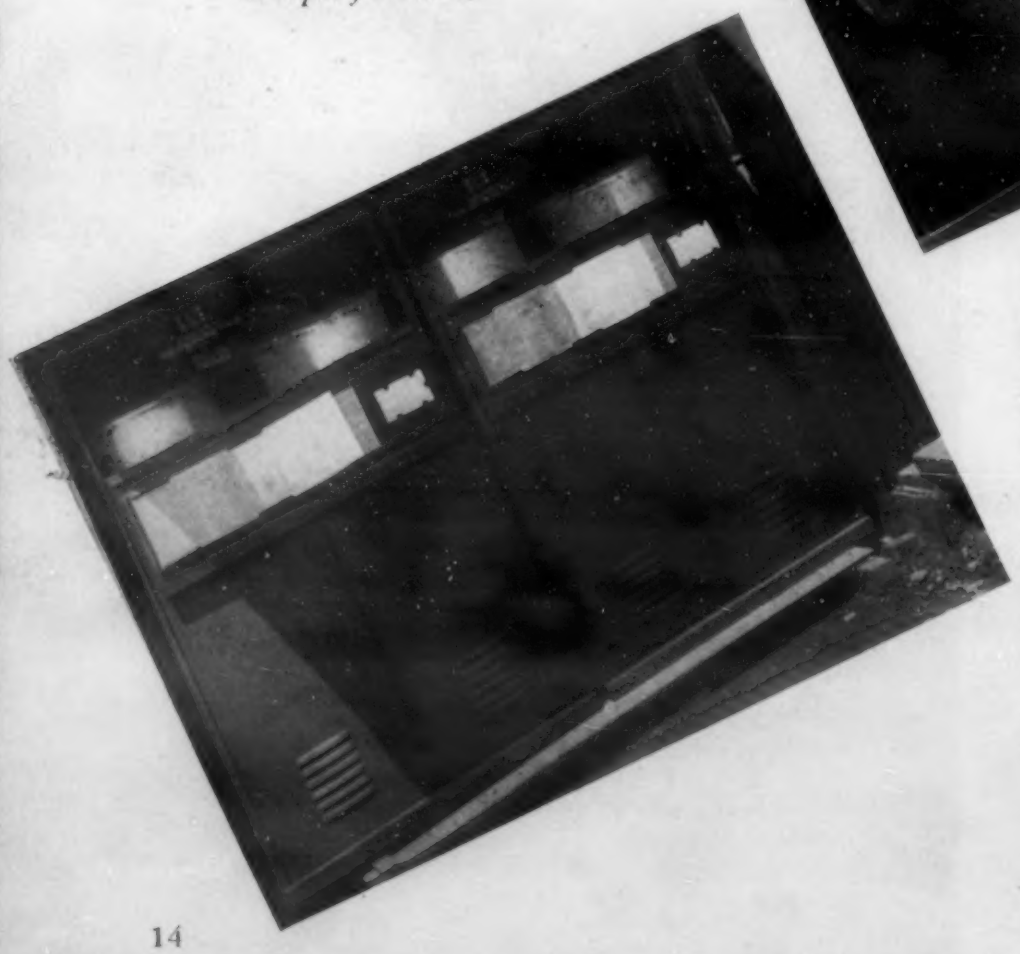


Fig. 3. Outdoor Housing for "Pyrofax" Gas Cylinders as Installed at Frick Company's Plant.

standpoint, *i.e.,* capable of being machined and of being made in one piece. These the heat resistant alloy producers have been supplying for many years, and with our modern knowledge of the intricacies, capabilities and limitations of such alloys, and with the recent rapid development of efficient carburizing machines, furnaces and auxiliary equipment, the future for gas carburizing seems bright indeed.

That the application of gas carburizing comes at the expense of the time-honored pack hardening method, there is no doubt, but it should be remembered that the latter will continue for many years to be widely used and will probably never be entirely replaced, particularly for heavy work,

by either gas or salt bath carburizing. Liquid bath case hardening is seldom feasible for very heavy cases, but is ideal for light cases (up to 0.025 in.) and extremely useful for medium cases (up to 0.040 in.), particularly where the amount of work to be handled is insufficient to warrant the use of gas carburizing. Gas carburizing, however, is more amenable to continuous set ups, is generally useful for batch work involving large volume, is less messy than the usual salt bath installation and offers excellent wear resistance and other case properties. The overall cost of gas treatment is occasionally lower than salt bath, but this is frequently less important than other factors in the selection of a carburizing method.

Carburizing with Pure Propane

In order that a gas be considered ideal for commercial carburizing, it must be rich in carbon, uniform in composition and free from moisture or other undesirable impurities. The gases that are most widely used include city gas, natural gas and hydrocarbons (pure propane or occasionally butane). *City gas* is available in many cities or large industrial centers, but its performance as a carburizing medium has frequently been so erratic, either because of its complex nature, the non-uniformity of its general composition or excessive moisture content, that for many jobs it is not suitable. Where available, it is usually employed for heating the furnaces. Because the amount of gas used in the retort for carburizing is so small as compared to the amount used for fuel, it would be generally impracticable for the gas company to revise its specification to make the manufactured gas suitable for carburizing. Almost all *natural gas,* however, is a good carburizing medium, although there are some areas where the available supply is not suitable. *Pure propane,* because of its particular chemical nature and uniformity, is an ideal gas for carburizing purposes.

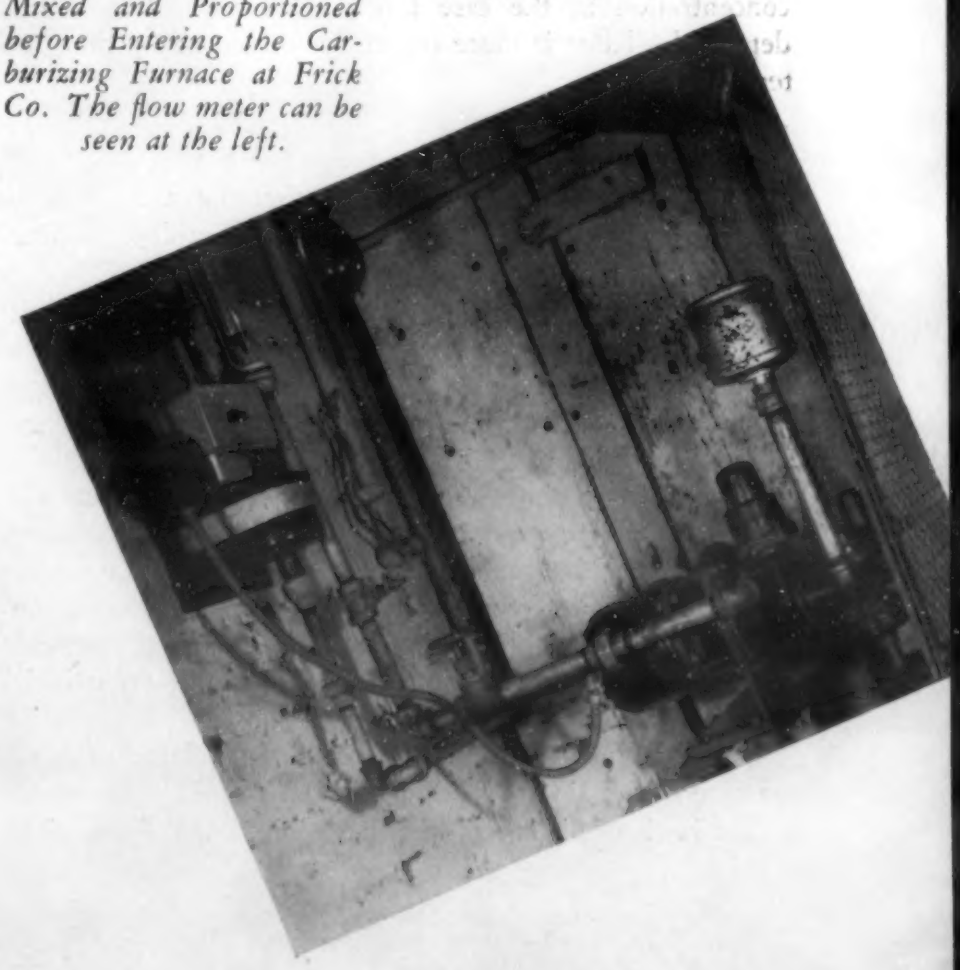
The general practice followed in using propane is somewhat similar to that used with other types of gas carburizing, but differs in many details because of the difference in activity among the gases. This article describes specifically the process and practice of carburizing with *"Pyrofax"* gas. (Process disclosed in American Gas Furnace Co. patents.)

"Pyrofax" gas is a liquefied hydrocarbon, essentially propane, constant in composition and exactly reproducible from cylinder to cylinder. The carburizing process using "Pyrofax" gas, developed and perfected by Carbide and Carbon Chemicals Corporation in cooperation with the American Gas Furnace Co., Elizabeth, N. J., during the past twelve years, offers all the advantages associated with gas carburizing in general, with the added advantage of uniformity of results due to uniformity of the gas composition. "Pyrofax" gas, because of its high carbon content, produces considerable excess free carbon or lampblack when cracked in the retort. In order to diminish this effect, the gas is diluted with air, ordinarily in the ratio of 1 volume "Pyrofax" gas to 2 parts air, before introduction into the retort. A baffle plate is usually installed at the rear end of the retort, against which the incoming mixture of "Pyrofax" gas and air impinges. This baffle plate is so located that a small space is formed in which the mixture is preheated to furnace temperature and pre-cracked before contact with the work.

The cycle employed in carburizing with "Pyrofax" gas and the subsequent heat treatment vary according to the specific requirements of each job. In some instances the carburizing gas is admitted to the cold furnace for a few minutes to remove air from the retort, then shut off until the work reaches temperature. "Pyrofax" gas is an extremely active carburizing agent; for that reason, cases high in carbon are readily produced. Some control of the carbon content is accomplished by regulation of the air-gas ratio. However, where cases relatively low in carbon are required, this can be further accomplished by diffusion. In doing this, the gas-air mixture is shut off at the end of the run, or after proper depth of case has been obtained and the furnace operated at full heat for enough time (usually ½ to 1 hr.) for the excess carbon to diffuse into the case. The case depth is also slightly increased during this operation. The heat treatment cycle used—direct quench from furnace; double quench; or cool in furnace, reheat and quench—bears, of course, no direct relation to the carburizing method, but is a function of specific case and core properties required.

As just stated, with "Pyrofax" gas as with natural gas or other hydrocarbons, the carburized case tends to have a relatively high carbon content. This, of course, is subject to the effects of original carbon content of the steel, car-

Fig. 4. Selas Gas-Air Mixing Machine in which "Pyrofax" Gas and Air are Mixed and Proportioned before Entering the Carburizing Furnace at Frick Co. The flow meter can be seen at the left.



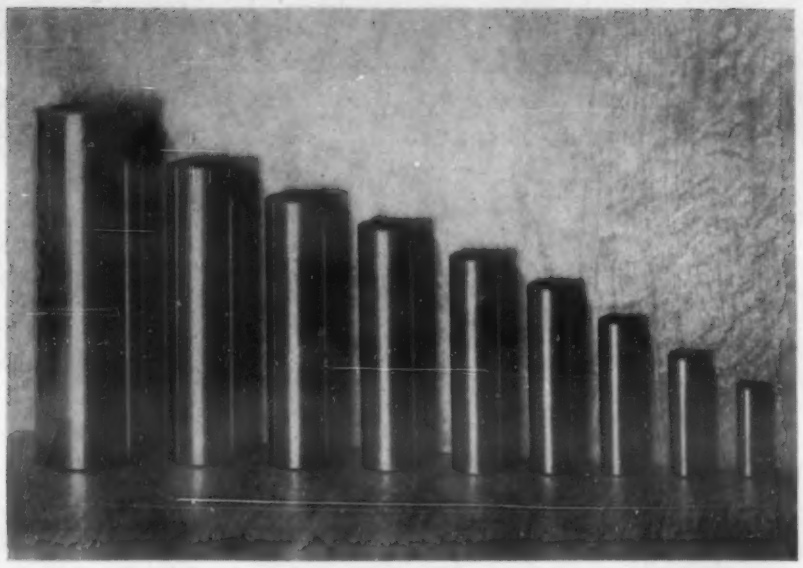


Fig. 5. Some of the Piston Pins Carburized by Frick Co. with "Pyrofax" Gas. The smallest pin is 1/2 in. in diameter.

burizing temperature and carburizing plus diffusion time. Assuming a given temperature, a given steel and a given carburizing gas, there is a theoretical surface carbon content in equilibrium with the carburizing gas. The equilibrium is not reached in practice because the carbon supplied to the surface diffuses inward and increases case depth until, however, a certain point is reached after which case depth increases but slowly while the carbon content of the case increases, approaching the surface value. The use of a gas with a greater percentage of carbon, such as "Pyrofax" gas, raises the equilibrium carbon content at the surface of the steel and thus increases the carbon content of the case at any point, after the same time interval. The depth of case obtained after any given time is somewhat, but not greatly, affected by the use of a richer gas. In other words, everything else being the same, a richer gas affects the carbon concentration in the case much more than it does case depth; the latter is more markedly influenced by time and temperature.

Equipment Used

The "Pyrofax" gas equipment consists of a pressure regulating device, mounted outdoors in a steel cabinet or housing, which also houses the gas cylinders (see Fig. 3) each of which contains 100 lbs. of "Pyrofax" gas. The gas pressure in the cylinders depends, of course, on the temperature of the environment; *e.g.* at 70 deg. F. the pressure is approximately 115 lbs. gage, while at 0 deg. F. the pressure is approximately 25 lbs. gage. The regulator reduces this pressure to about 6 oz. and serves to maintain this constant pressure on the line leading into the building. There is a positive pressure on the "Pyrofax" gas cylinders at temperatures as low as minus 44 deg. F., so that a continuity of gas supply is maintained at any atmospheric temperature that could reasonably be expected; no artificial heater or auxiliary generator is required.

The "Pyrofax" gas is led from the regulator at 6 oz. pressure to the air-gas mixing machine (see Fig. 4), where it is mixed with air and discharged into the lines. The customary mixture is 1/3 "Pyrofax" gas and 2/3 air. The mixing machine feeds the mixed gas to the carburizing furnace at a pressure of 1 1/4 to 15 lbs.

We are indebted to Frick Company, Waynesboro, Pa., for permitting us to observe their installation and for information concerning their experience with it. The following description of this company's practice, which is typical of "Pyrofax" gas carburizing, will illustrate the method and indicate some of the advantages which may be obtained when applied to this type of work in this kind of furnace.

The Frick Company's Practice

Frick Company have, for the past 18 months, been using "Pyrofax" gas chiefly for carburizing piston pins. They use a stationary vertical (pit type) furnace and pass the gas and air mixture directly into the carburizing retort. The general cycle includes heating the work to temperature, admitting carburizing gas for the carburizing period, then shutting off the "Pyrofax" gas-air mixture and the fuel gas, and allowing the work to cool in the furnace. The piston pins range in diameter from 1/2 in. to 5 in. (see Fig. 5); the following is a typical analysis of the steel used:

	Per Cent
Carbon	0.15
Silicon	0.18
Manganese	0.98
Phosphorus	0.078
Sulphur	0.071

The Furnace Employed

The furnace used by Frick Company (see Figs. 1 and 2) is a product of the American Gas Furnace Co., Elizabeth N. J., and is similar to their vertical carburizers used throughout industry for this type of carburizing where it is not practical to employ rotary retort equipment.

The retort is of cast 60 Ni/15 Cr heat resistant alloy and has an available heating space 15 in. in diameter and 30 in. deep, with a bottom inlet extending below the furnace through which the mixture of "Pyrofax" gas and air is introduced. The top of the retort has a shoulder for clamping the cover securely in place, in which is provided a fixed orifice for escape of spent gas.

The retort sets in a conventionally-designed cylindrical furnace shell with an insulating refractory lining, backed by block insulation; this type of insulation results in reduced gas consumption as compared with earlier designs in which specially molded hard burned brick linings were backed with insulation.

The large number of small burners fire tangentially into the combustion space so that heat is liberated all around the retort and over the entire height from top to bottom to give higher efficiency and to permit accurate control of the temperature over the entire retort. The burners are of heat resisting alloy and fire into sillimanite burner tunnels; the use of alloy burners results in much reduced corrosion, oxidation and growth as compared with those of cast iron. The burners are subdivided into three independent sections to simplify the balancing of temperatures.

Automatic temperature control is achieved by means of an American Gas Furnace Co. high-resistance millivolt meter type controller, which operates in conjunction with a regulating valve in the air line, easily adjustable for desired maximum and minimum input. The valve permits maximum fuel input when coming up to temperature and automatically resets and controls the temperature within narrow limits after maximum has been reached.

In the carburizing gas line, the "Pyrofax" gas is mixed with air, in the proportions 35 per cent gas/65 per cent air in a Selas mixing machine (see Fig. 4). The proportioned gas mixture then passes through a calibrated and graduated tapered-tube flow meter, the amount of gas passing being indicated by the position of a float riding on the gas stream.

The carburizing gas enters the furnace through the inlet at the bottom. Just below the bottom of the work fixture in the retort a baffle plate is placed, which serves to preheat and pre-crack the gas, and on which much of the excess soot is deposited before it reaches the work. After passing over the work the gas leaves the furnace *via* a fixed orifice at the top. Control of the flow of carburizing gas is maintained by adjustment of a valve at the Selas mixing machine; the nominal flow of carburizing gas mixture through the Frick Company's furnace is 50 cu. ft. per hr. at 1¼ lbs. gage pressure; this amounts to 17.5 cu. ft., or about 2 lbs. per hr. of "Pyrofax" gas.

The work fixtures, one of which is illustrated in Fig. 2, were developed by the Frick Company. All parts of the fixture are of low-carbon steel; they consist of 3 round perforated plates with 4 vertical rods and a center tube containing an eye in it for removal. The open construction and simplicity of these fixtures make them well adapted for a wide variety of work.

The Carburizing Cycle

The usual practice of the Frick Company is to load and light the furnace at about 6 A.M. By 8:30 A.M. the temperature setting of the control (1700 deg. F.) has been reached; the actual temperature of the work is about 1670 deg. F. At this point the carburizing gas mixture is turned into the retort, and the flow maintained at the control valve at the mixing machine. After 6 hrs. the fuel and carburizing gases are shut off, and the pins allowed to cool in the furnace. When cool, they are removed, reheated to 1450 deg. F. and quenched in water. An operating log, taken from a series of production runs during December 1937, is shown in the Table.

The case produced by this 6-hr. treatment is about 0.060 in. deep, with a Rockwell C reading of 62-65 after hardening. In this, as in all applications of this method, the case is uniform in properties along each piece and from piece to piece, as well as uniformly graded across the piece. As with any other well-controlled gas carburizing job, the case is extremely resistant to spalling.

Frick Company formerly employed box carburizing, which required 16 to 18 hrs. to produce the 0.060 in. case. The total time required for carburizing with "Pyrofax" gas is approximately 8½ hrs. Frick Company estimates that with their former method the overall cost was approximately 13 cents per lb. of work, and with the present method, 4 cents per lb.; thus, a saving of 9 cents per lb. of work is indicated, which is believed to be due to three factors:

1. The relatively small amount and low cost of "Pyrofax" gas required, namely about 2 lbs. per hr.
2. The saving in time, which results in large economy in overhead, fuel gas required, labor costs, etc.
3. The ability to carburize a greater number of pins per load in the present method. Using box carburizing, the company was able to load only 12 pins in each box. Reference to the Table will show that by the present method they are able to carburize from 28 to 180 pins per load, depending on the size of pins

Conclusion

The decision to replace any existing box carburizing setup with a gas carburizing unit is not one that can be made lightly. The engineer faced with the problem should carefully appraise his present equipment, as to both its physical condition and the results obtained with it. The cost of acquiring a carburizing installation that does a really satisfactory job—either through modernizing the existing equipment or purchasing a brand new gas carburizer—should be determined. Then, the initial cost of the new equipment should be balanced against the improvement in quality, increased production and overall savings effected in using it. As to the particular kind of gas to use for carburizing, pure propane offers distinct advantages of excellent, controllable case properties and absolute case uniformity that merit wider consideration.

Operating Log of "Pyrofax" Gas Carburizer at the Frick Company for December, 1937

Date	Start Heat	Furnace at 1700 Deg.	Carburizing Gas On	Shut Off Furnace	Shut Off Carburizing Gas	Total Weight of Load	Number of Pins Per Load
12-1-37	6 A.M.	8:10 A.M.	8:10 A.M.	2:30 P.M.	2:30 P.M.	320 lbs.	60
12-2-37	6 A.M.	8:30 A.M.	8:30 A.M.	2:30 P.M	2:30 P.M.	320 lbs.	60
12-3-37	6 A.M.	8:30 A.M.	8:30 A.M.	2:30 P.M.	2:30 P.M.	314 lbs.	60
12-6-37	6 A.M.	9:30 A.M.	9:30 A.M.	3:30 P.M.	3:30 P.M.	246 lbs.	36
12-7-37	6 A.M.	8:30 A.M.	8:30 A.M.	2:30 P.M.	2:30 P.M.	246 lbs.	36
12-8-37	6 A.M.	8:30 A.M.	8:30 A.M.	2:30 P.M.	2:30 P.M.	294 lbs	48
12-9-37	6 A.M.	8:30 A.M.	8:30 A.M.	2:30 P.M.	2:30 P.M.	294 lbs	48
12-10-37	6 A.M.	8:30 A.M.	8:30 A.M.	2:30 P.M.	2:30 P.M.	294 lbs	48
12-13-37	6 A.M.	8:45 A.M.	8:45 A.M.	2:45 P.M.	2:45 P.M.	230 lbs.	28
12-14-37	6 A.M.	8:30 A.M.	8:30 A.M.	2:30 P.M.	2:30 P.M.	230 lbs.	28
12-15-37	6 A.M.	8:15 A.M.	8:15 A.M.	2:30 P.M.	2:30 P.M.	230 lbs.	28
12-21-37	6 A.M.	8:00 A.M.	8:00 A.M.	2:00 P.M.	2:00 P.M.	180 lbs.	180
12-29-37	6 A.M.	8:30 A.M.	8:30 A.M.	2:30 P.M	2:30 P.M.	156 lbs.	145
12-30-37	6 A.M.	8:45 A.M.	8:45 A.M.	2:45 P.M.	2:45 P.M.	172 lbs.	155
12-31-37	6 A.M.	8:00 A.M.	8:00 A.M.	2:00 P.M.	2:00 P.M.	113 lbs.	106

Improving Aircraft Propellers by Surface Rolling

By G. Sachs

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IN SPITE OF THE FACT that magnesium is only about two-thirds as heavy as aluminum, the favorite metal for aircraft purposes is aluminum. The reason for this is that the high strength magnesium alloys are subject to serious reductions in their actual strength by corrosion and other factors. Therefore the conventional mechanical properties of the magnesium alloys have not the same meaning and value for the designer as have the properties of duralumin or steel.

For magnesium castings, some remedies could be found in extensive research and practical development work, and their application is steadily growing. Sheets and forgings, however, in magnesium alloys are only used for minor purposes and low stressed parts.

The real reason for this unsatisfactory situation is not yet quite clear. The actual visible corrosion of magnesium can be prevented by chromate treatment, which is generally used. But, obviously, this protection is not sufficient to bring wrought magnesium alloys up to a state so that an engineer can apply them with the same degree of safety as aluminum, steel or any other metal. As in the case described in this paper, special methods have to be developed to get the full benefit out of the low specific gravity of magnesium.

Magnesium Propellers

One very interesting field for magnesium is in aircraft propellers. To follow the trend of development propellers have continuously to be increased in size, and it is the general opinion today that aluminum is already too heavy for very big propellers. However, even in modern airplanes

Figs. 1 and 2. Broken Magnesium Propeller.

Fig. 3. Erosion Pittings on the Shaft of a Magnesium Propeller.

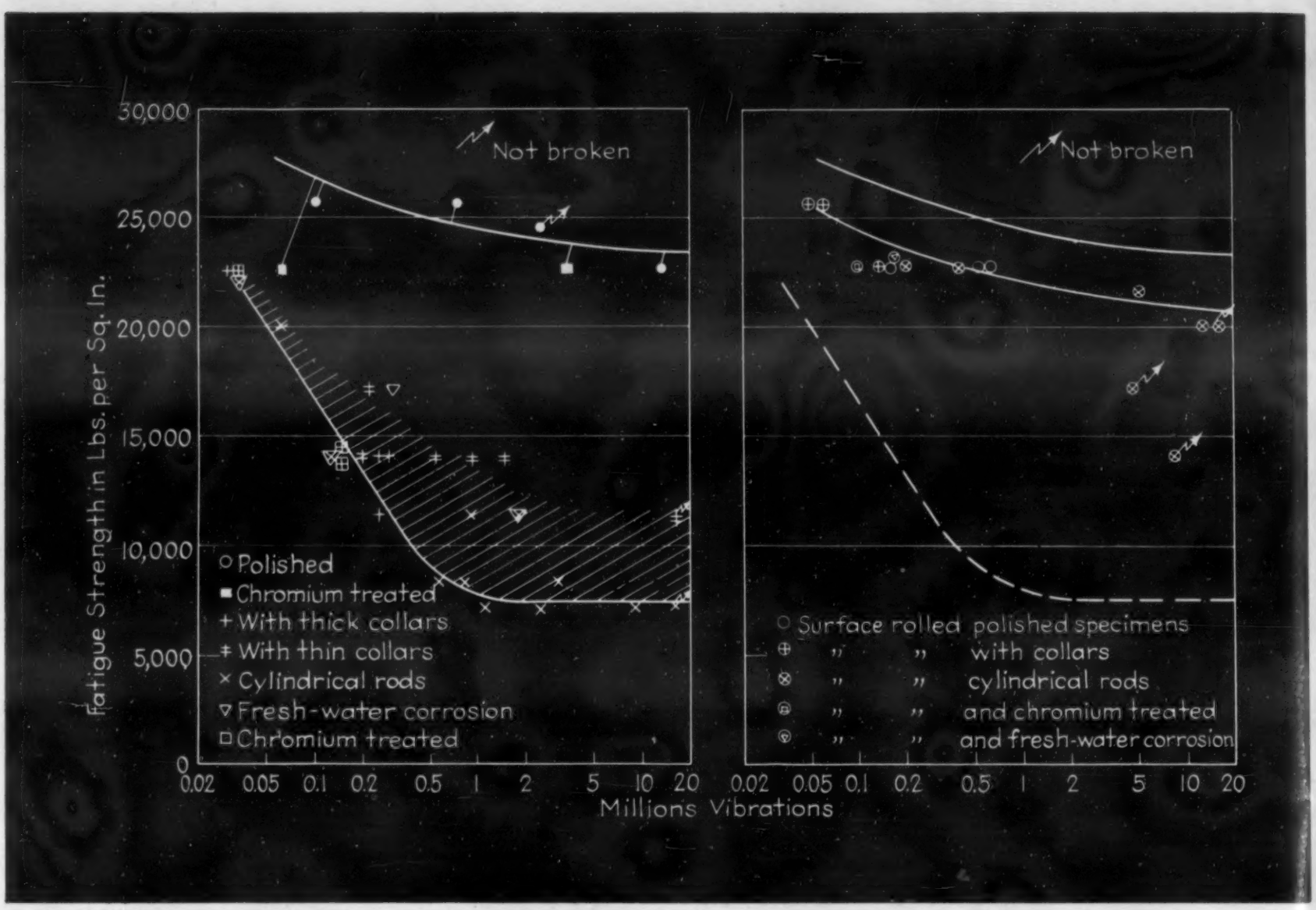


Fig. 4. (left) Influence of Different Factors on the Fatigue Strength of a Magnesium Alloy in a Rotating Beam Type Testing Machine.

Fig. 5. (right) Influence of Different Factors on the Fatigue Strength of a Magnesium Alloy in a Rotating Beam Type Testing Machine.

the strain is sometimes high enough to cause serious failures in aluminum and steel propellers. These difficulties could be overcome by slight changes in the design and assembly of the propeller and the engine.

Probably, in many countries, serious efforts have been made to introduce magnesium propellers. But up to the present time the same experience was probably encountered in every case. Out of a number of propellers used in competition with aluminum, an alarming fraction of magnesium propellers broke after a short time of service. Figs. 1 and 2 show such a failure.

The following conclusions may be drawn from these pictures:

1. The failure is a typical fatigue failure caused by vibration.

2. The fatigue crack starts at a point where the shaft sticks out from the hub.

3. The surface of the propeller shaft around the broken surface is pitted deeply, especially at the starting point of the crack and the point opposite to it.

Unbroken magnesium propellers, mounted in hubs, are as a rule also pitted, as in Fig. 3, sometimes very seriously, sometimes less. The dust worn off the magnesium has a color similar to a corrosion product. This type of material deterioration may be called "erosion," as it is caused by some combination of mechanical and corrosive attack. The main factor is the sliding of the magnesium on the steel, caused by the elastic vibrational deformations of propeller and hub.

Small Scale Fatigue Tests

The appearance of the fracture in Figs. 1 and 2 proves definitely that such failures are caused by vibrations. The static loads are comparatively small and in no way sufficient to cause such failures. Actually, their effect is negligible.

A number of small scale fatigue tests (of the rotating-beam type) were made, to find out the main factors which reduce the fatigue strength of magnesium alloys. Some specimens had, as customary, a reduced portion in the center of ½ to ⅝ in. diameter but, for some experiments, cylindrical specimens of about ⅞ in. diameter were used.

According to Fig. 4 the following results were obtained (the alloy used contained 8 per cent aluminum and 0.5 per cent manganese, balance magnesium):

1. The standard fatigue strength (for 10,000,000 vibrations) of polished specimens was 23,000 lbs. per sq. in (=100%).
2. Simultaneous corrosion with fresh water reduces the fatigue strength to about 50 per cent.
3. By attaching a stiff collar around the central portion of a specimen the fatigue strength is reduced to approximately 30 per cent (7,000 lbs. per sq. in.)
4. With cylindrical specimens which break in the holder, the same low value was obtained.
5. Simultaneous corrosion had no influence on the fatigue strength of cylindrical specimens or specimens with an attached collar.

In the last three cases a steady flow of white dust, worn off the specimens by the steel collar or steel holder, was produced.

Additional experiments were made to find methods of improving the fatigue strength of specimens with collars or cylindrical specimens with the following results:

6. Chromate treatment of the magnesium has no visible influence on the fatigue strength. However the wear was reduced appreciably.
7. Using thin flexible collars with carefully rounded off edges gave somewhat higher fatigue strength, up to about 50 per cent of the standard value.
8. Thin intermediate layers of fibre or similar materials gave also an improvement of about the same degree. Besides, this addition eliminated the wear practically completely.

Surface Rolling

A very effective method to improve the fatigue strength of parts which are subjected to an erosive action was found in the so-called "surface rolling."[2] This method consists in deforming the surface skin of the material with one or several rolls in a similar way as a bar is treated in a roller straightener. The rolls are pressed against the rotating bar and advance with a certain speed (or the bar advances) so that a close overlapping thread is formed. The pressure however has to stay within such limits that the reduction of the diameter will be negligible. With magnesium alloys this limit is rather definite, as at higher pressure the surface will be damaged and chips formed. Even at lower pressure such damage may occur if the rolls are not perfectly smooth and if the lubrication is not sufficient.

With the small scale specimens this pressure could not be adjusted to a definite value. The pressure must have been somewhere near to the maximum as some specimens were damaged. The results of the experiments with surface-rolled test pieces are reproduced in Fig. 5.

With polished specimens treated this way the fatigue strength was reduced slightly to about 90 per cent of the standard value (to 21,000 lbs. per sq. in.).

Specimens with collars attached and cylindrical specimens had practically the same fatigue strength. The effect of the erosion is counterbalanced completely by surface rolling. The improvement of the eroded test pieces amounts to 80 to 200 per cent. Even damaged specimens were improved to the same degree. Simultaneous corrosion also had no influence.

The formation of dust by abrasion, however, was in no way reduced. As the stresses in these tests are generally higher than with untreated specimens, much more dust was formed. Similar results were also obtained with duralumin. The reduction of the fatigue strength by erosion, however, is smaller with duralumin than with magnesium.[3]

Surface Rolling in Manufacturing

The next problem was to confirm the results of small scale experiments under conditions which correspond to those of the practical application. Besides, the rolling process for propellers and the optimal working conditions had to be developed.

For propellers of a shape shown in Figs. 2 and 3, which have a cylindrical shaft in the region of high stresses, a simple method for surface rolling was developed by the author. The propeller is placed in a horizontal lathe in the same manner as for a machining operation. The rolling device consists, according to Fig. 6, of a ring in which three hydraulic cylinders are inserted. The cylinders are evenly spaced and the ring is slipped over the propeller. The rolls are attached to the pistons. The cylinders are filled with oil and the pressure is regulated in all

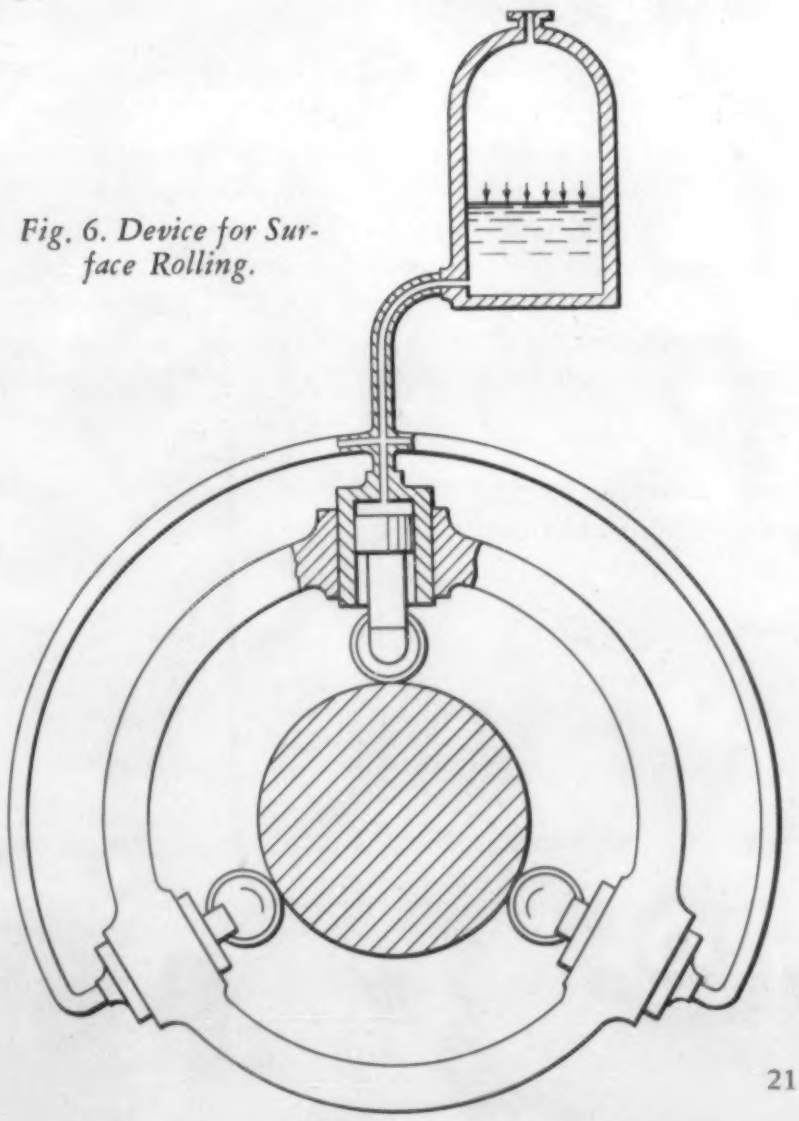


Fig. 6. Device for Surface Rolling.

three cylinders uniformly by air pressure. The rolling device is mounted on the support of the lathe and advances like an ordinary cutting tool.

In their final shape the cylinders can be tilted to about 30 deg. for rolling tapered shafts. Devices suitable to roll diameters up to 8 in. were built. For the rolling of threads and fillets a special equipment with a single tiltable roll was designed.

The shape of the ordinary rolls is shown in Fig. 7. The advance was about 0.004 in. per revolution; this gives an actual working surface for each roll of $\frac{0.004 \text{ in.}}{3} = 0.0013$ in. width. In this way a very smooth mirror-polish, free from rolling marks, was obtained, if the shaft was polished before the rolling operation. During this operation the surface has to be flushed abundantly with oil and the rolls have to be kept clean by a wiper arrangement, which removes the dust which is worn off from the magnesium.

It is advisable to start and finish the rolling without pressure and to step it up to the working value over a length of about ½ in. In most cases the shaft was rolled twice, advancing to left and to right; the second rolling, however, is of a minor importance. The shaft diameter is reduced by about 0.0005 in., probably due only to abrasion and by smoothing of the surface.

In the beginning of practical manufacturing the suitable pressure was determined by increasing to a value which damaged the surface. About one-half of this dangerous pressure (300 lbs.), see Fig. 8, was regarded as suitable for actual production. However, the experiments described in the next paragraph show that it is worthwhile to increase the working pressure as high as possible.

Full Scale Experiments

To make experiments on a full scale special equipment, designed for determining the vibration characteristics of engines and propellers, was available.[4] The set-up used to investigate propellers consists of a short cylindrical shaft with similar elastic properties as an engine crankshaft to which a vibrating adjustable unbalance is mounted. The propeller is attached in the usual way to the end of the shaft. By varying the frequency of the vibrations the amplitude of the propeller vibrations can be regulated to any desired value; this value is kept constant by a special stop.

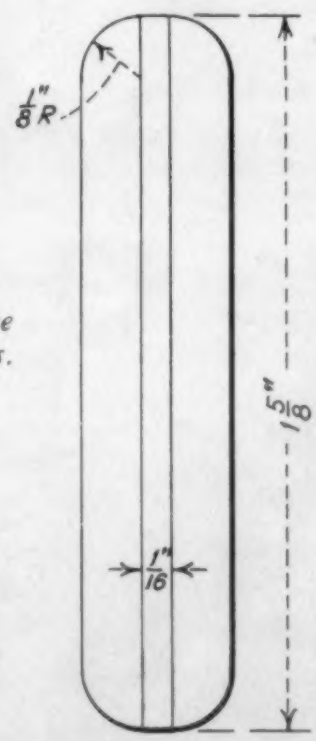


Fig. 7. Shape of the Rolls.

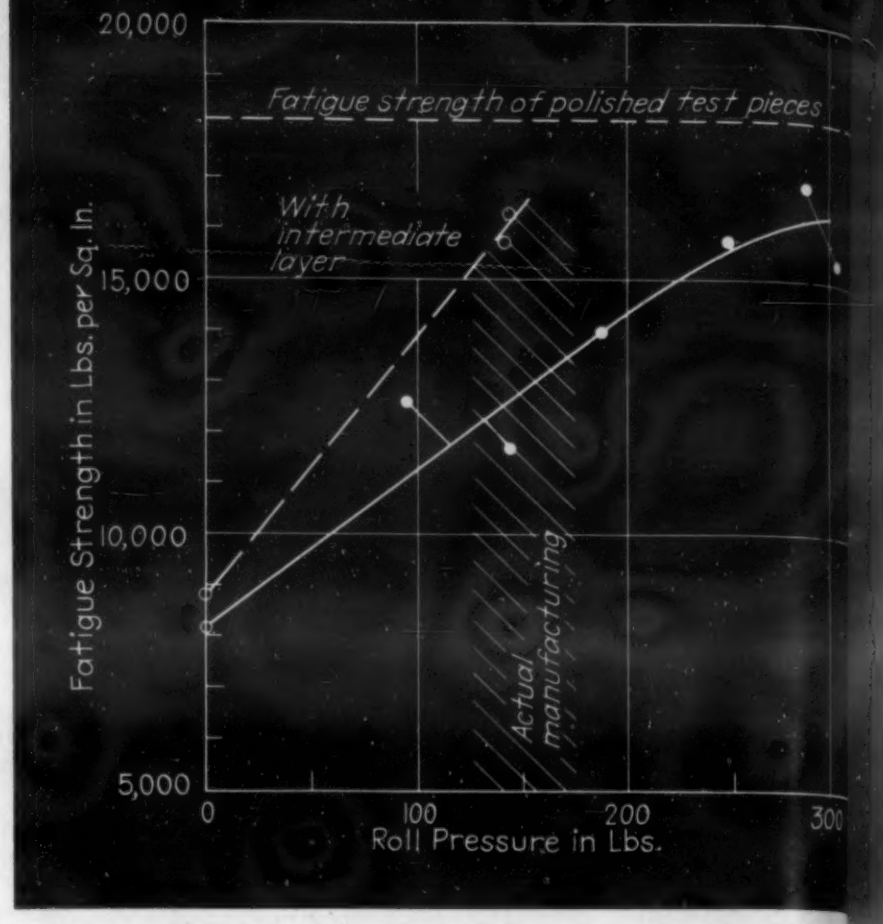


Fig. 8. Fatigue Strength of Magnesium Alloy Rods, 2¾ in. Diameter, Surface Treated by Rolling.

However, a few experiments with genuine propellers resulted in failures near the tip. Such failures also occur sometimes in actual flying and are attributed to resonance vibrations of the propeller blade itself. The shaft failure may be caused by some other type of vibrations enforced by the engine crankshaft.

With magnesium propellers only shaft failures occurred. To get this type of failure with the available testing equipment and also to make the test pieces as simple as possible, cylindrical bars were used. One end of these bars was machined to the shape of the shaft. However, with these specimens many failures of the hub occurred, so that a special thick hub had to be used instead of a genuine one.

A systematic investigation was made with about 30 test pieces, consisting of extruded rods, about 3 in. in diameter and 40 in. in length. The shaft had the same shape and dimensions as the propellers, shown in Figs. 2 and 3. Two to four identically treated specimens were subjected to stresses of different values and the fatigue strength for 10,000,000 vibrations extrapolated.

Confirming the small scale experiments, the following results were obtained according to Fig. 8. (As standard value, the fatigue strength of small specimens machined out of these test pieces = 18,000 lbs. per sq. in., is used.)

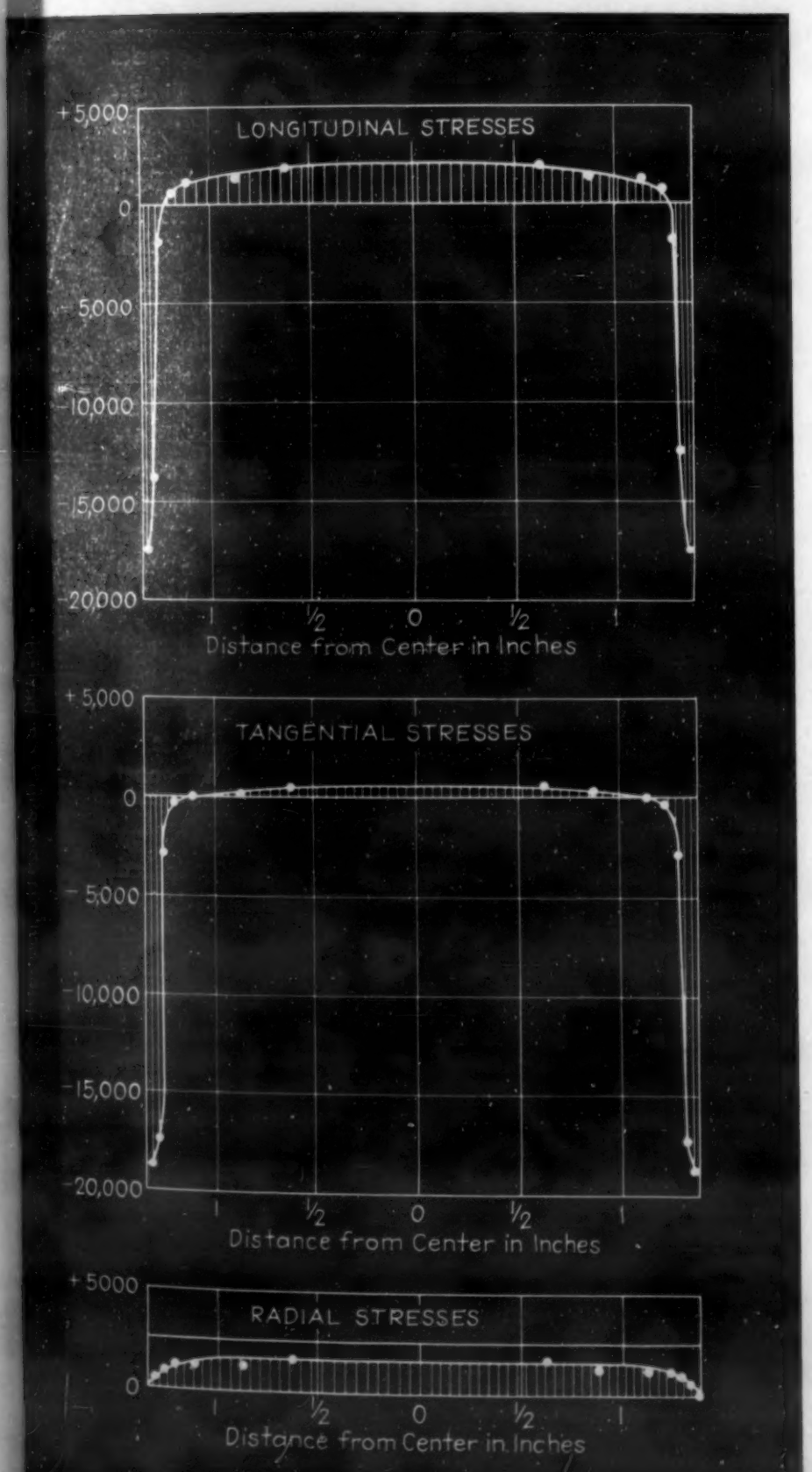
1. The fatigue strength in the propeller shaft is reduced to about 45 per cent of the standard value = 8,000 lbs. per sq. in.

2. Surface rolling partly eliminates this reduction, so that values between 65 and 85 per cent were obtained. The higher the rolling pressure, the higher is also the fatigue strength. Damages of the surface had no influence.

3. An intermediate layer of fibre of about 1/8 in. thickness increased the fatigue strength of untreated test pieces by about 10 to 50 per cent of the standard value.

4. An intermediate layer of fibre increased the fatigue strength of material, surface rolled under manufacturing conditions, to about 85 per cent.

Fig. 9. Internal Stresses in a Surface Rolled Magnesium Propeller.



Fatigue strengths up to 16,000 lbs. per sq. in. or up to 90 per cent over the value of untreated test pieces can therefore be obtained under optimum working conditions. However, the present practical conditions do not guarantee an improvement over 50 per cent. Such an improvement was found also in a later developed testing equipment with genuine propellers (from 7,000 to 104,000 lbs. per sq. in.). With propellers of a large size—diameter of the shaft 4¼ in.—the improvement was about the same; the actual values however were very low (4,600 and 7,000 lbs. per sq. in., respectively).

In the experiments without an intermediate layer of fibre, the surface of the shaft was worn off badly, in one case as much as 0.040 in. in diameter. Even then the fatigue strength of surface rolled specimens was not reduced.

Internal Stresses Introduced by Surface Rolling

The protection of propeller shafts by surface rolling, which process was introduced and developed by the author about 4 yrs. ago, is probably the first case where this interesting new process was applied in practice. Up to the present the factor, which really causes the improvement of the fatigue properties, is not quite clear. There may be some real improvement in the properties of the surface layer by cold deformation.[2] But a more convincing theory considers as the main factor the building up of compression stresses in the surface layers by surface rolling, which are generally found to be very useful in overcoming the defects when tensile stresses and corrosive or erosive attack occur simultaneously.[5] Such compression stresses are actually created in surface rolling.[6]

To determine the internal stresses a test piece 2¾ in. in diameter and 10 in. in length was cut off from a rod, which was surface rolled under manufacturing conditions. This test piece was bored out; this way the diameter of the hole was gradually increased and after each operation the change in length and in diameter was measured. The complete distribution of the internal stresses can be calculated from these deformations by the author's method.[7]

The internal stresses are shown in Fig. 9. As expected, high compression stresses are present in a surface layer of about 0.040 in. thickness, as well in the longitudinal as in the tangential direction, of surface rolled magnesium alloy propellers.

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ENDURANCE OF ANNEALED GOLD and a Quenched Dental Alloy

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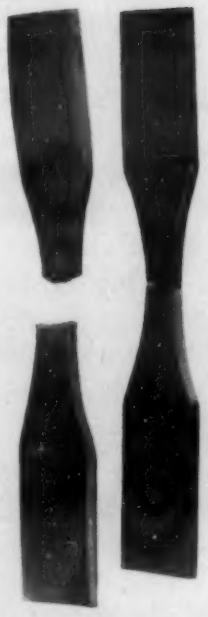

Surprisingly few data have ever been published on the fatigue properties of dental alloys. Such properties, namely the endurance limit and the resistance to overstress, are of some importance in the selection of dental alloys. The authors have determined the endurance limit in completely reversed bending of annealed pure gold and a quenched dental alloy by the use of a "baby" Upton-Lewis type of endurance machine.—The Editors.

Fig. 1. (Above) Test Specimens Used in the Investigation.

Fig. 2. "Baby" Upton-Lewis Type of Endurance Machine.

ORTHODONTIC DEVICES AND CLASPS of artificial dentures may be subjected to a large number of cycles of repeated stress in chewing, or to a smaller number of cycles of stress, usually very much greater, in springing the appliance out of place and back into place when it is fitted to the mouth or removed for cleaning or repair. Both the endurance limit and the resistance to overstress are therefore of importance in the selection of alloys for such dental service.

Endurance limits of the alloys commonly tested by metallurgists are determined in rotary or reversed bending, the endurance limit being stated in terms of half the stress range. It denotes the highest stress to which the metal or alloy can be subjected in service for an arbitrarily chosen number of cycles of reversed bending without showing any signs of failure. For example, if the stress at the endurance limit runs from plus 20,000 to minus 20,000 lbs. per sq. in., the endurance limit is given as 20,000 lbs. per sq. in.

Previous Investigations

The scanty data on the endurance limits or fatigue of dental golds have not been obtained in the usual manner just mentioned. Coleman[1] chose to test a series of eight dental gold alloys at the extremely high stress of $\pm$100,000 lbs. per sq. in. in reversed bending. In the quenched (tough) condition his alloys broke in from 4,000 to 41,000 cycles and in the slow-cooled (hardened) condition at 15,000 to 88,500 cycles. Thus only highly overstressed conditions were studied, as 10,000,000 cycles of reversed bending is the usual criterion for non-ferrous alloys.

Peyton[2] studied three cast dental golds in repeated flexure, from zero to a positive stress only. Therefore, his endurance limit values should, if the positive stress was not too high, be about twice as high as the half-stress-range values reported in the usual studies. He studied one alloy

in the slow cooled (hardened) condition having 260 Brinell and 97,000 tensile and found an endurance of 0 to 51,500 lbs. per sq. in. Of two other alloys in the quenched (soft) condition, one of 127 Brinell, 78,000 tensile, gave 0 to 61,000 lbs. per sq. in. endurance. The other of 135 Brinell and 70,000 tensile gave 0 to 59,000 lbs. per sq. in. endurance. Both of these values were above the proportional limits which were respectively 55,000 and 40,000 lbs. per sq. in. Even when calculated on the usual half-stress-range basis, these endurance ratios of the quenched alloys are higher than one usually finds for non-ferrous alloys. It is of some interest to know if the endurance ratio (ratio of endurance limit to tensile strength) is higher for gold alloys than that common for other non-ferrous alloys.

Materials and Procedure

We have determined the endurance limits in completely reversed bending of pure annealed gold and of a dental gold alloy. In view of the scanty data in the literature on the subject, even these fragmentary data are worth putting on record.

The tests were made on flat specimens 0.035 in. thick, necked down as shown in Fig. 1, longitudinally polished, and tested in a "baby" Upton-Lewis type of endurance machine as shown in Fig. 2. The specimens were subjected to completely reversed cycles of bending.

The stresses were computed from the machine constants, the spring calibration, and the dimensions of the test piece in the usual manner. A life of 10,000,000 cycles of reversed bending was taken as the criterion of the endurance limit.

The materials tested were: (1) Wrought pure gold, annealed at 500 deg. F. for 30 min. and furnace cooled; (2) a wrought alloy designated as "TT" containing 6.25 Cu, 12.75 Ag, 6 Pt, and 75 per cent Au, water quenched after holding 30 min. at 1400 deg. F. The properties were as shown in Table I. These data show that the endurance ratio of the pure annealed gold is 26 per cent and that of the "TT" alloy is 40 per cent. The endurance values are shown in the S-N curves of Fig. 3, the data for which are given in Table II.

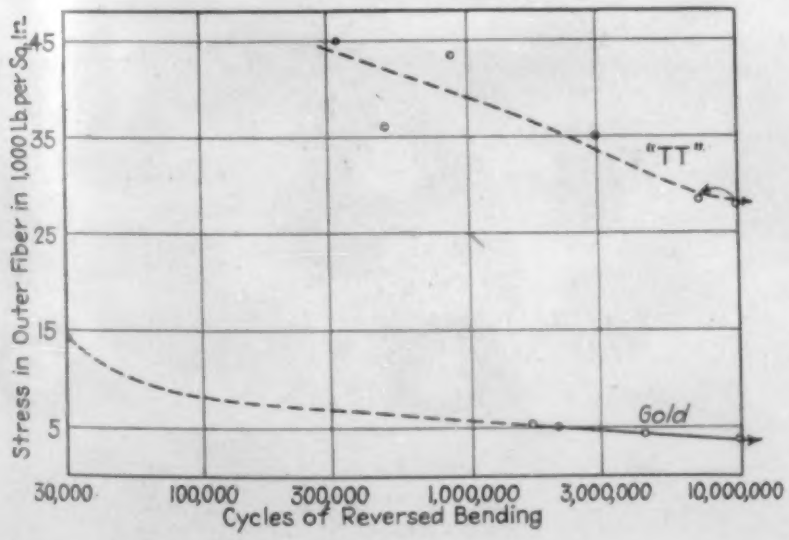

Fig. 3. The S-N Curves Showing The Endurance Values.

TABLE I—Properties of Materials Tested

Material	Tensile strength	Yield point	Elong., 1 in. gage, per cent	Brinell	End. limit, lbs. per sq. in.
Gold	17,680	None Detected	33.0	28.0	4,600
"TT"	71,800	49,100	26.5	115.0	28,500

TABLE II—Data for the Endurance Values

Pure Annealed Gold

Specimen No.	Stress (lbs. per sq. in.)	Cycles	
1	14,200	30,640	
2*	2,703	10,789,200	(unbroken)
3	5,600	2,170,800	
4	4,742	4,406,400	
5	5,937	1,749,600	
6†	4,500	12,960,000	(unbroken)

* Specimen showed no signs of failure after 10,789,200 cycles so stress was increased to 5,600 lbs. per sq. in.
† No signs of failure after 12,960,000 cycles.

"TT" Alloy

Specimen No.	Stress (lbs. per sq in.)	Cycles	
1	45,000	324,000	
2	43,700	874,800	
3	36,300	486,000	
4	35,200	2,948,400	
5-A	28,450	10,000,000 +	(unbroken)
5*	28,598	7,663,200	

* Specimen first stressed at 28,450 lbs. per. sq. in. and run beyond ten million cycles, after which the stress was increased to 28,598 lbs. per sq. in.

Conclusions

The endurance ratio for the pure gold, 26 per cent, is in the usual range for non-ferrous alloys. The ratio for the "TT" alloy, 40 per cent, is even higher than those found by Peyton for quenched alloys when it is recalled that his values are for the zero-to-maximum stress range only. The ratio obtained for the "TT" alloy in this work approaches the usual value for steel.

No direct comparisons can be made with Coleman's or Peyton's data since Coleman's alloys were much lower in gold and Peyton's were both lower in gold and much higher in copper.

Acknowledgments

The work herein reported was done as part of the work for an undergraduate thesis at the University of Minnesota and the authors wish to express their appreciation for the opportunity of publishing the results. The authors are especially indebted to Dr. H. W. Gillet for his helpful suggestions in the preparation of this paper.

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EFFECT OF VERY SMALL ADDITIONS TO Transformer Steel

by W. S. Messkin

and J. M. Margolin

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The reader on the Editorial Advisory Board, who reviewed this article before publication, remarks that no reference is made to the work of Yensen, who has shown the importance of the effect of very small amounts of carbon, and that, until the indications are confirmed on really low-carbon material, the results as to effect of vanadium should be taken as suggestive only.

He states that good silicon-iron may show a coercive force of 0.1 oersted, compared with 0.27 oersted, the lowest figure reported in the article, so that the effect of the additions should be studied on material that is of higher quality without the additions.

This does not affect the interesting data on the effect of the additions on the crystal arrangement.—H.W.G.

OTHER ELEMENTS BESIDE SILICON have been added to transformer steel in the hope of improving magnetic and other properties. Most of the efforts along this line have involved rather large additions of aluminum[1, 2, 3] and of aluminum plus manganese.[4] The influence of very small quantities of addition elements has been shown by many workers [5–12] to influence the primary and secondary crystallization of ferrous and non-ferrous alloys.

A preliminary investigation was made on the effect of such additions to 4 per cent silicon transformer steel. The elements chosen were Al, Ti, V and Be. The iron base was ingot iron of about 0.05 per cent C to which the elements were added as 70 per cent ferrosilicon, metallic aluminum or beryllium, and ferrotitanium with 20 per cent Ti, 5 per cent Al.

Effects of these additions could be related to their influence on crystallization, degasification or deoxidation. In order to throw light on the part played by degasification, one series of melts was made in vacuo, another in air. High

Fig. 1. Structure of Steel No. 1. No additions. 40X.

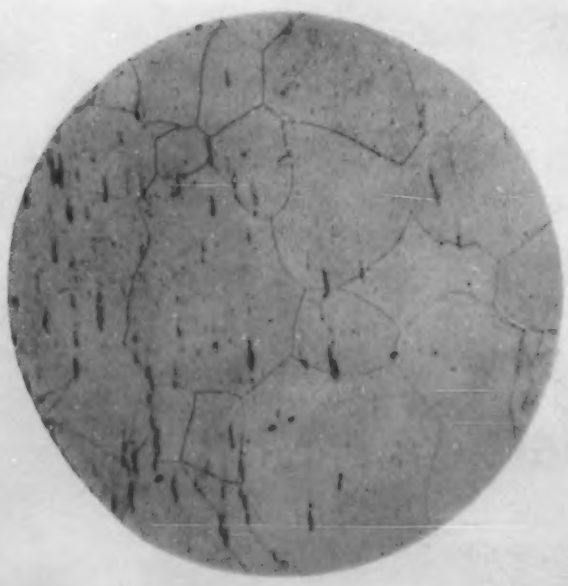

Fig. 2. Structure of Steel No. 9. Ti(0.05%) added. 40X.

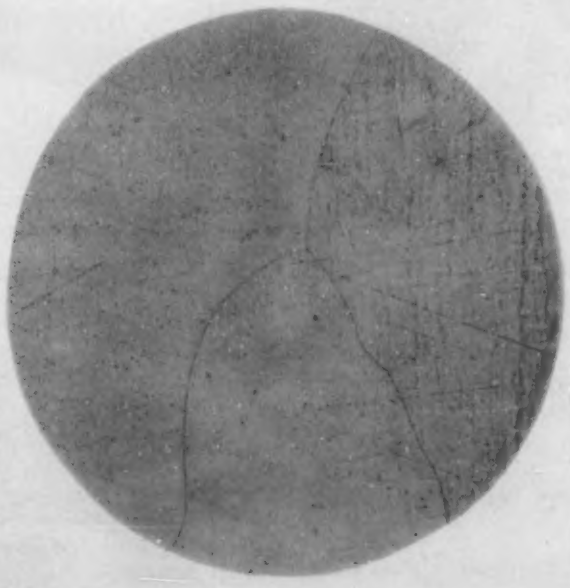

Fig. 2a. Structure of Steel No. 7. V(0.055%) added. 40X.

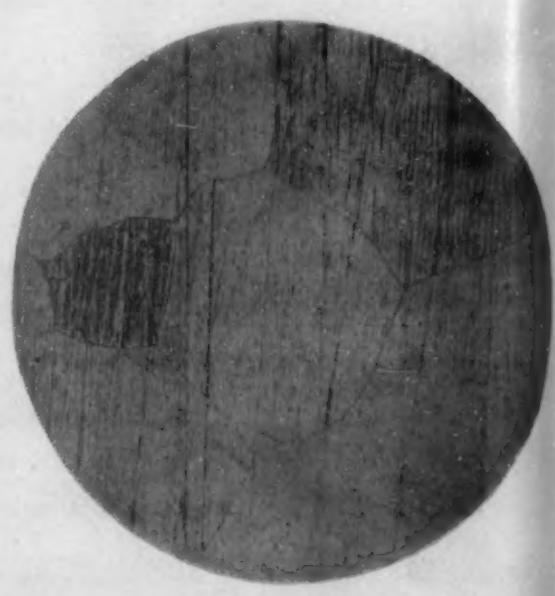

Fig. 3. Macrosection of Vacuum Melted Ingot with No Additions.

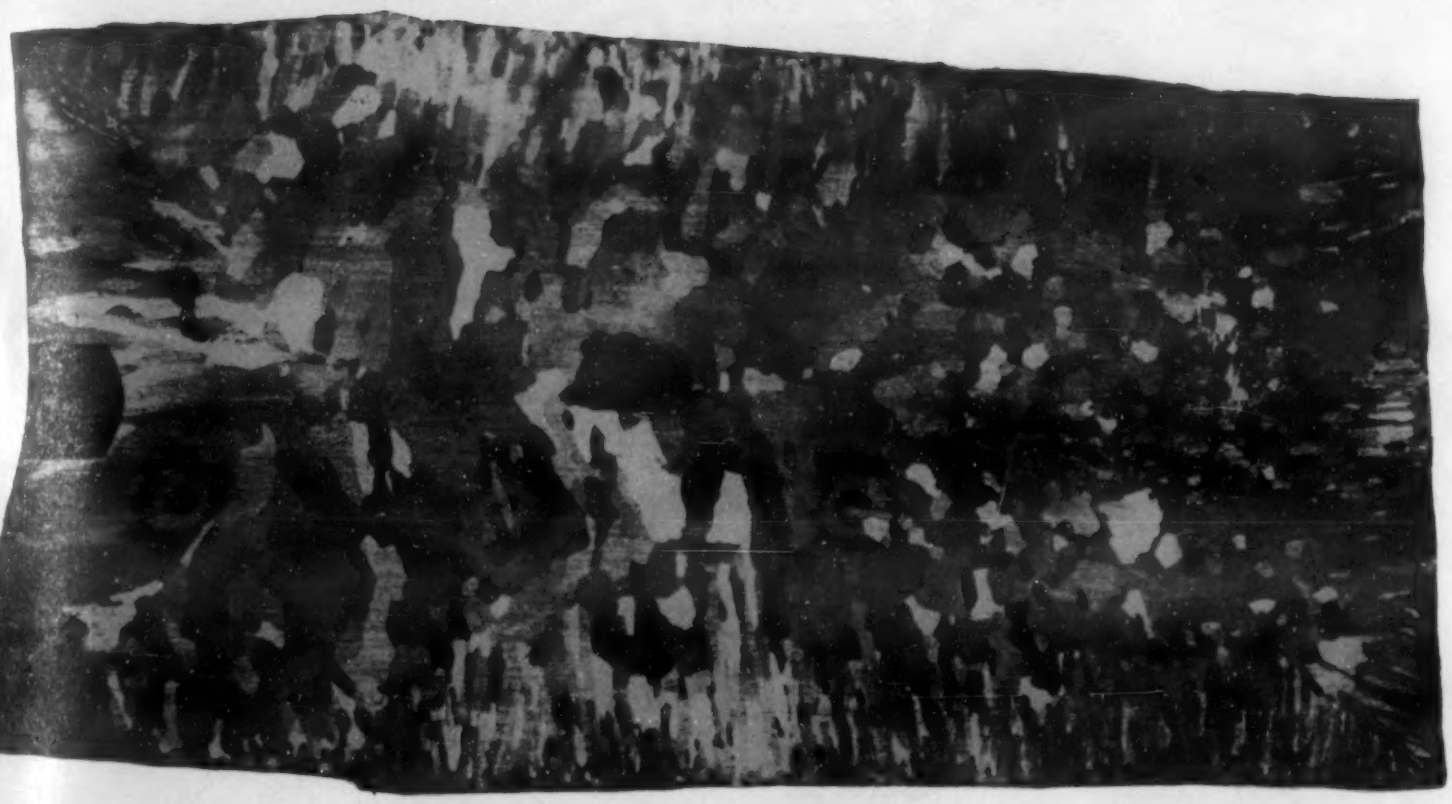

Fig. 4. Same as Fig. 3 except 0.04 Per Cent Al Added.

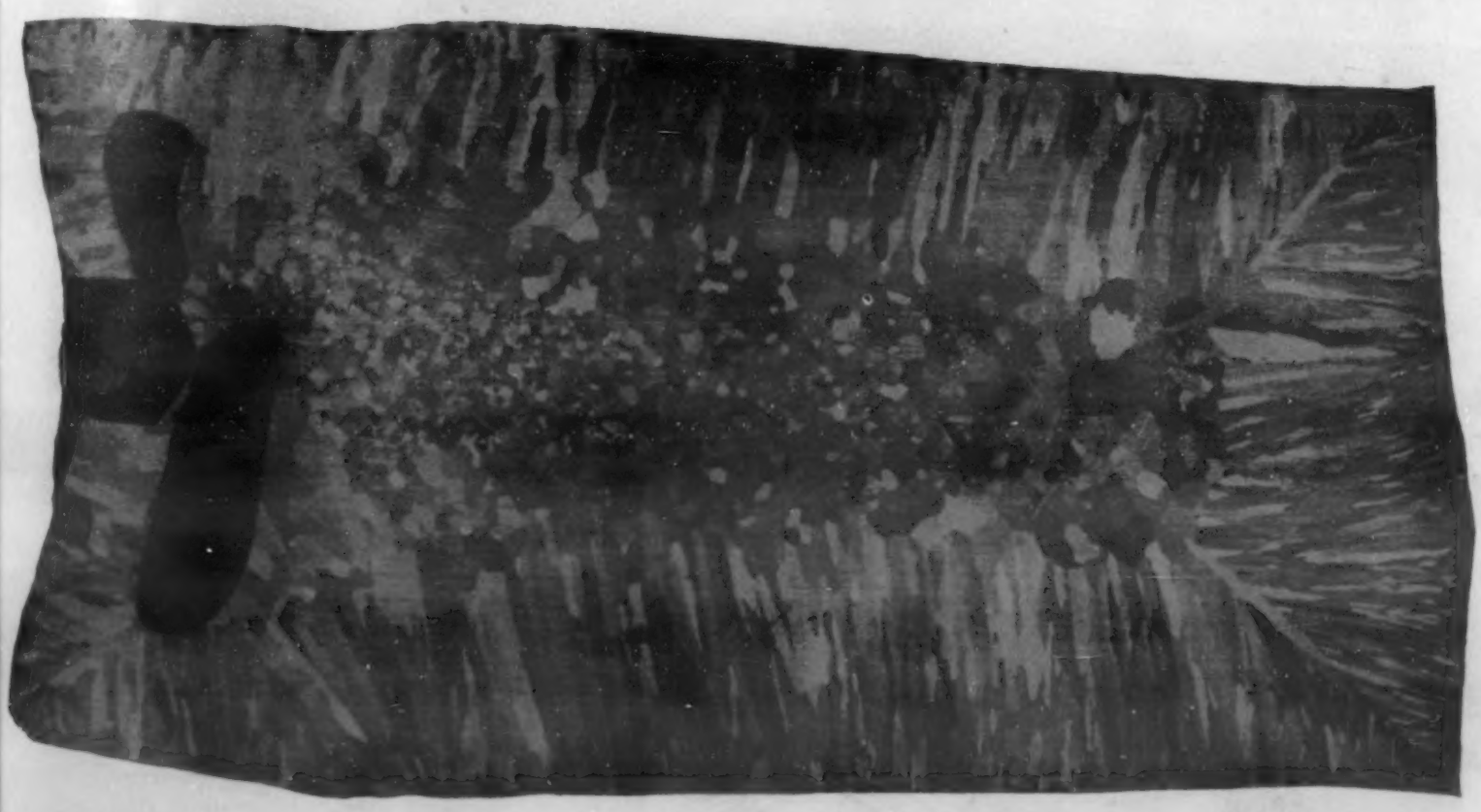

Fig. 5. Same as Fig. 3 except 0.07 Per Cent Al Added.

Fig. 6. Same as Fig. 3 except 0.09 Per Cent Al Added.

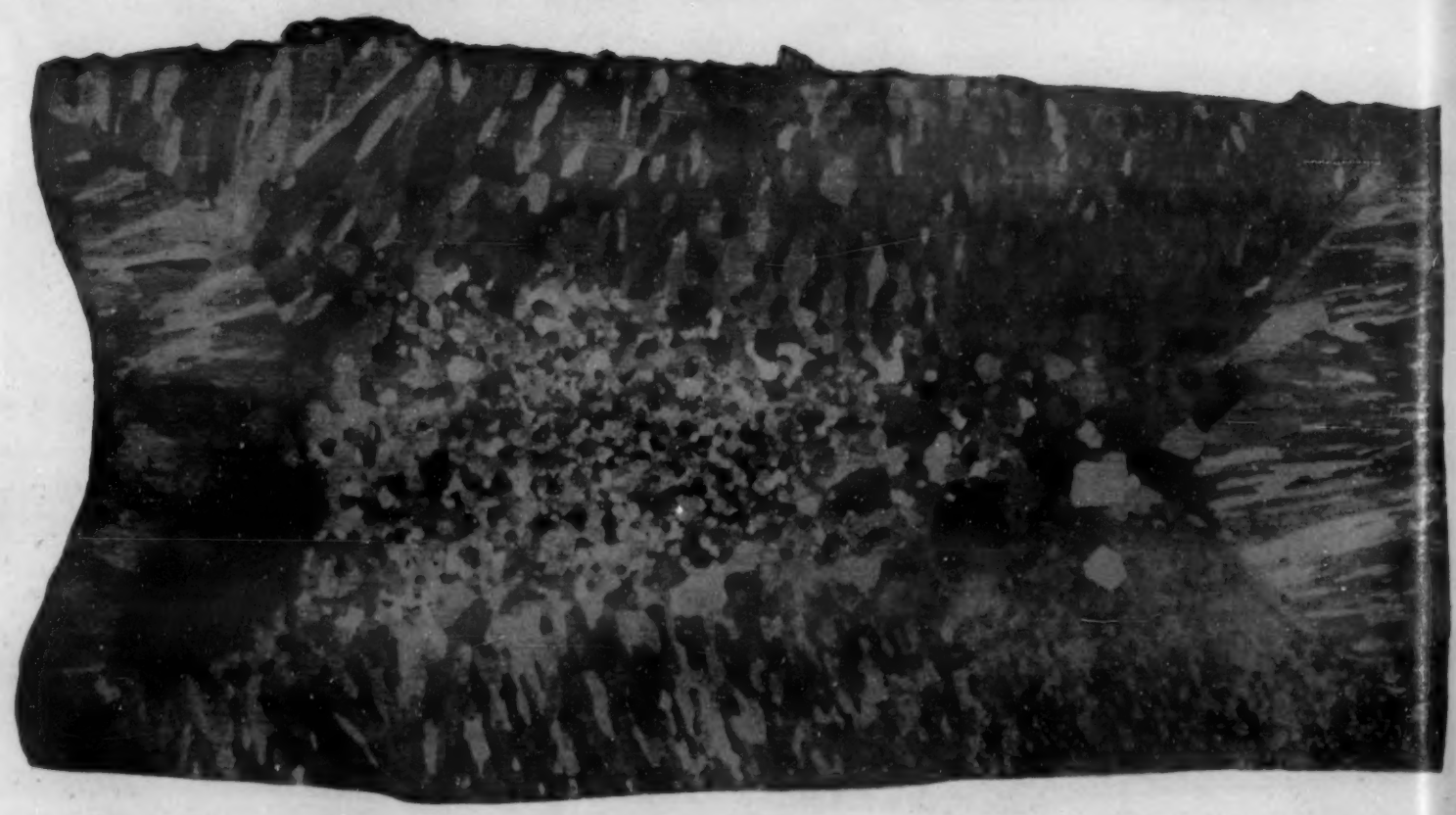

Fig. 7. Same as Fig. 3 except 0.023 Per Cent V Added.

Fig. 8. Same as Fig. 3 except 0.055 Per Cent V Added.

Fig. 9. Same as Fig. 3 except 0.02 Per Cent Ti Added.

frequency melting in an acid crucible was used. The vacuum melted alloys were cast in air into round ingots weighing 11 kg. (25 lbs.). Those melted and cast in air weighed 15 kg. (33 lbs.) and had a greater ratio of height to diameter. Pouring temperature for all was 1470 to 1480 deg. C. (2680 to 2700 deg. F.).

The ingots were cut lengthwise and one half macro-etched in boiling 20 per cent HCl. The second half was also split lengthwise and forged down. From the forgings slices 6.5 x 6.5 mm x 20 cm long were cut for magnetic testing. The magnetic property determined was coercive force, since this property would give a clue to the magnitude of the hysteresis loss in transformer service. The lower the coercive force, the lower the hysteresis loss. Coercive force was measured by the ballistic method in an open circuit.

Table 1.—Vacuum-Melted

No.	Composition by Analysis, Per Cent			Added, Per Cent			Coercive Force Hc-Oersteds	
	C	Mn	Si	Al	V	Ti	Single Treatment	Double Treatment
1	0.06	0.02	4.30	...	...	...	0.67	0.66
2	0.03	0.02	3.82	...	...	...	0.69	...
3	0.04	0.04	4.35	0.04	...	...	0.66	0.58
4	0.04	0.06	4.25	0.07	...	...	...	0.76
5	0.04	0.02	4.32	0.09	...	...	0.53	0.47
6	0.04	0.05	4.18	...	0.023	...	0.59	0.63
7	0.03	0.05	4.18	...	0.055	...	0.47	0.27
8	0.04	0.03	4.32	0.005	...	0.02	0.63	0.68
9	0.03	0.04	4.50	0.012	...	0.05	0.55	0.48

The vacuum melted alloys were tested in two conditions (single treatment), annealed at 820 deg. C. (1510 deg. F.) for 2½ hrs., furnace cooled, and (double treatment), annealed at 1100 deg. C. (2010 deg. F.) for 40 min., air cooled, then 2½ hrs. at 820 deg. C. (1510 deg. F.) and furnace cooled.

Fig. 10. Same as Fig. 3 except 0.05 Per Cent Ti Added.

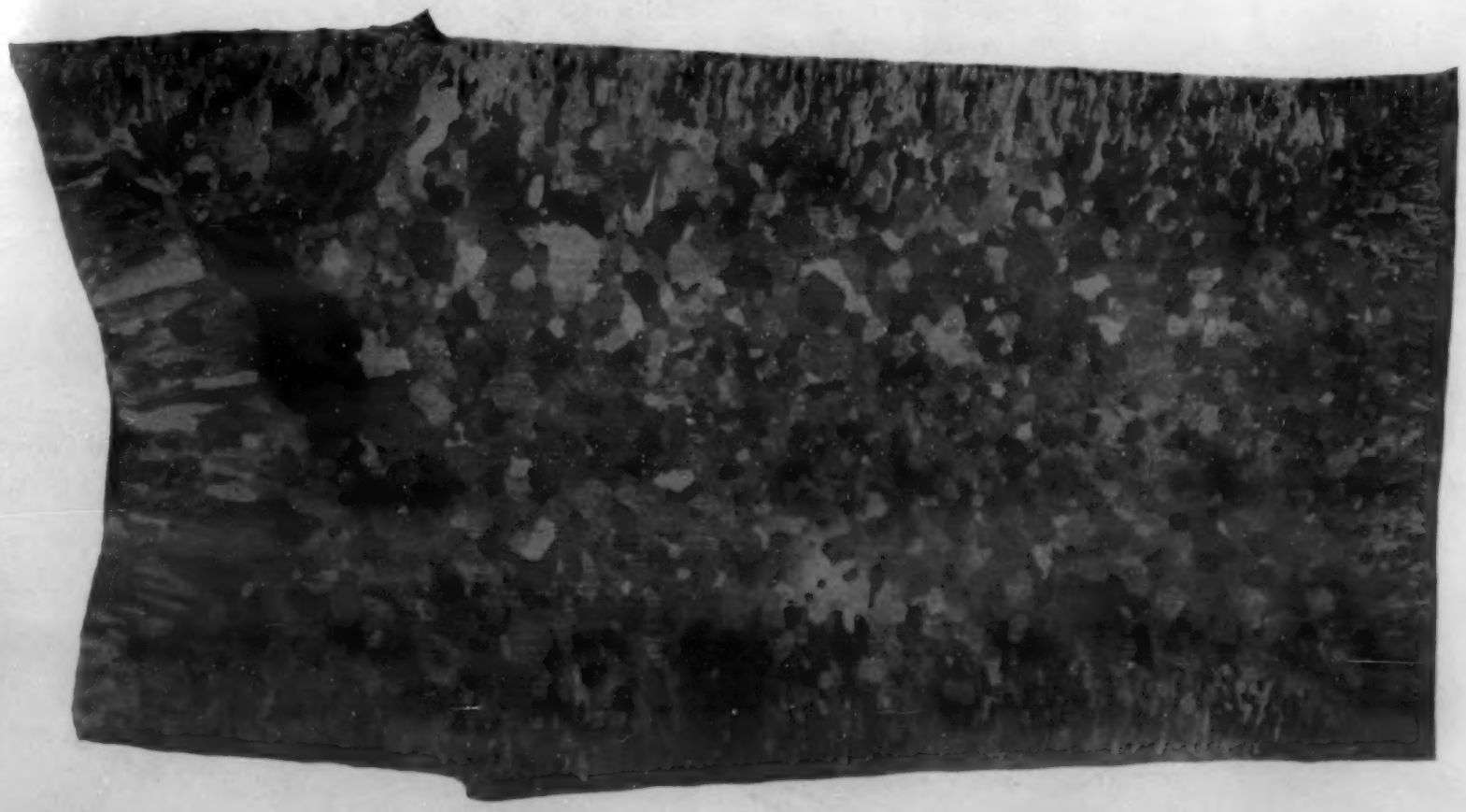

Fig. 11. Macrosection of Air-Melted Heats with No Additions.

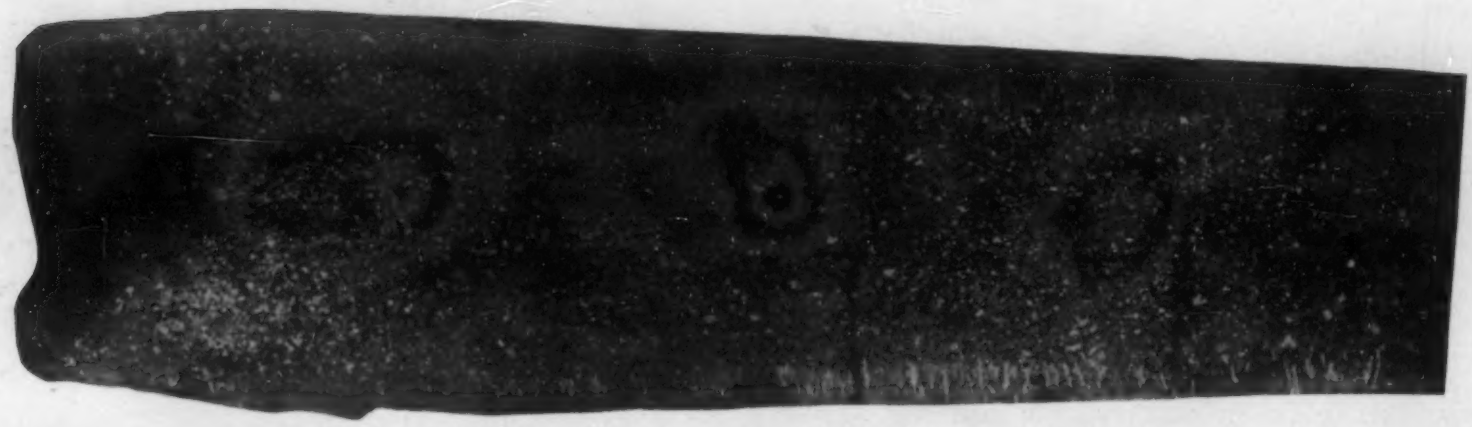

Fig. 12. Same as Fig. 11 except 0.03 Per Cent Ti Added.

Fig. 13. Same as Fig. 11 except 0.05 Per Cent Ti Added.

The 1100 deg. C. anneal was used with the purpose of securing diffusion of carbon, since some loss of carbon from the surface doubtless occurred during hot rolling. The compositions and coercive forces are listed in Tables 1 and 2.

Vacuum melting showed no advantage over melting in air. The addition of Al and Be showed no marked advantage. The larger additions of Ti had a slight beneficial effect. The most noteworthy effect resulted from the larger additions of V in steels Nos. 7 and 14, double treated.

Table 2.—Air Melted

	Composition by Analysis, Per Cent		Added, Per Cent				Coercive Force Hc Oersteds After
No.	C	Si	V	Ti	Al	Be	Double Treatment
10	0.07	3.99	...	...	...	...	0.65
11	0.08	4.19	...	0.03	0.008	...	0.60
12	0.04	4.03	...	0.05	0.012	...	0.40
13	0.07	4.30	0.03	...	...	...	0.55
14	0.06	4.20	0.05	...	...	...	0.35
15	0.07	4.30	...	...	...	0.03	0.55

Larger grain size and hence better coercive force in the double treated steels that had had small additions of Ti or V (Figs. 1, 2, 2a) may be due to the deoxidizing and degasifying influence.

The effect upon primary crystallization, i.e., ingot structure, and on piping, is shown in the macro-etched sections of Figs. 3-10 for vacuum melted ingots in which Fig. 3, transformer steel with no additions, shows submerged pipe all through the ingot. Fig. 4 with 0.04 per cent Al, shows no notable change.

As the Al is increased to 0.07 per cent, Fig. 5, and 0.09 per cent, Fig. 6, the pipe is more central and the crystallization largely columnar. The ingot has not been improved by the Al additions up to 0.09, per cent at which point the pipe is brought to the top.

Additions of 0.023 and 0.055 per cent V, Figs. 7 and 8, bring the pipe to the top and produce reduction

Fig. 14. Same as Fig. 11 except 0.03 Per Cent V Added.

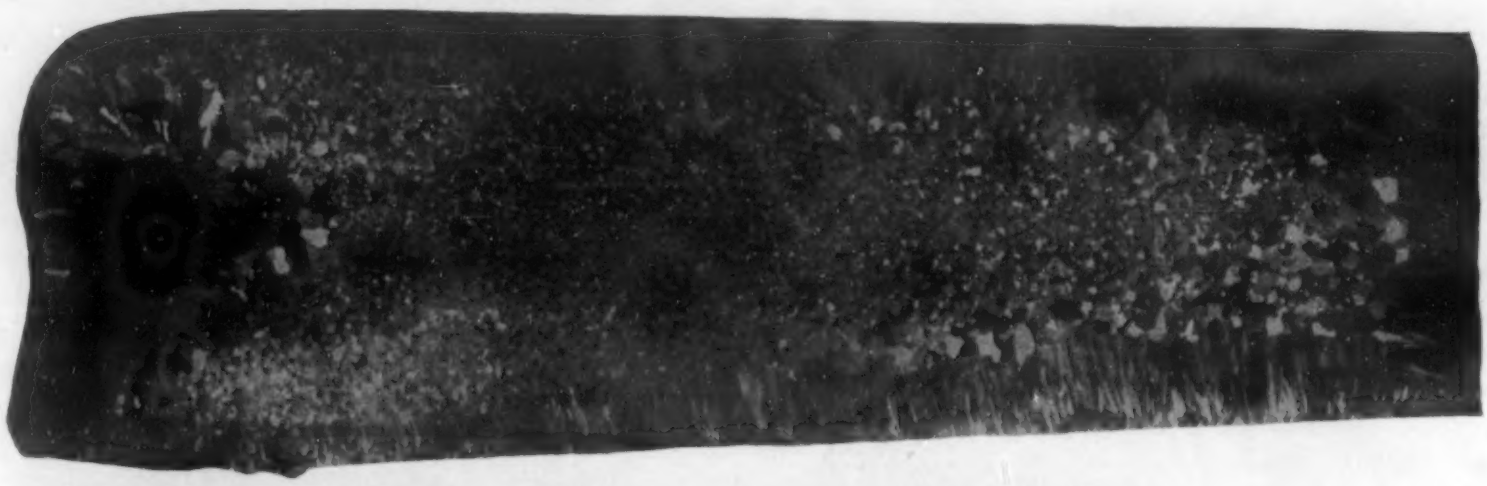

Fig. 15. Same as Fig. 11 except 0.05 Per Cent V Added.

Fig. 16. Same as Fig. 11 except 0.03 Per Cent Be Added.

in size of the equiaxed central zone of crystals but columnar formation at the edges is still pronounced.

The addition of 0.02 and 0.05 per cent Ti, Figs. 9 and 10, not only raises the pipe, but also reduces the columnar zone at the edges.

The same effects are seen in the larger ingots from air-melted heats, Figs. 11 to 16. The Ti or V additions again removed the secondary pipe and decreased the width of the columnar zone. Be was not as effective. The optimum dose of Ti or V cannot be decided from these laboratory experiments and must be determined on a commercial scale.

Distributed piping, instead of pipe brought to the top and cropped off, is doubtless responsible for much "blister scrap" during rolling, so that the production of correct piping is therefore second only in importance to the attainment of the desired magnetic properties.

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Editorial *(Continued from page A17)*

metallic. It is easy to think that the differences between the metals and the non-metals reside in the make up of the atoms and probably have something to do with electron arrangement or orbits. Here we personally bog down, because we can't remember how the inside of the atom looks to the physicist. But it is reasonable that the electrical conductivity, which is an attribute of the fully initiated metals, should be due to something peculiar about the atom-electron relation, that is, different from the set-up in the non-metals.

So we asked a physicist about this. What he told us was in terms of "permitted energy levels." As we translate his comments, he might mean that in any element in the solid state, valence electrons don't stay put with any one atom, they like all the atoms equally well and go visit them all impartially like honey-bees in clover. So an atom hasn't any pet, tame valence electrons in any set positions or orbits; it just has so many untamed valence electrons that happen to be visiting it at the time. The "bound" electrons that do have orbits, haven't much to do directly with conductivity.

Now if the clover field is a race track and a little whirlwind starts up, the whole mass of bees is set into a whirling motion but each bee still keeps on visiting various blossoms so that each clover plant still has its proper number but each bee is moving along with the wind as well as keeping up his earlier helter-skelter motion. The whirlwind is the applied voltage, the movement of the bee under its influence is the passage of current in the electric circuit. If the bees go ring-around-the-rosy under a little whirlwind, clover would be a metal and a good conductor.

In an alfalfa field—a non-metal—the bees won't start the may-pole dance till the little whirlwind increases to a regular tornado—a breakdown voltage that finally starts them.

But that doesn't tell us whether the difference is that these bees are bumble-bees, not so easily blown about, or whether alfalfa shields honey bees while clover doesn't. The physicist thinks it more likely that it is the combination of size and arrangement of the atoms in the crystal that gives very slight shielding in some cases—the metals, and very complete shielding in others,—the non-metals.

Well, this is a pleasant and fragrant scene, but it doesn't at all make clear to us why metals differ from non-metals. Anyhow the question wasn't "why is a metal?" so we don't have to answer it. We'll leave it to the next generation.

The question of when "impurities" shift a metal from that category into the alloy class is one we can't so blithely ignore, but we'll leave that for discussion when we tackle the second question.—H.W.G.

Electric Steel

Electric steel ingot production of the United States has reached a volume little realized by many. In 1937 the output of steel ingots from electric furnaces was 814,310 gross tons or the largest ever recorded, according to the American Iron and Steel Institute. In 1929 the production was only 532,392 tons. It also exceeds by a large margin the tonnage of ingots made in the acid open hearth—only 333,473 tons in 1937. Of interest also is the fact that electric steel, including estimated castings output, was 2.37 per cent of the country's total steel ingot and castings production (Table 3 in "Production Trends of American Alloy Steels and of Electric Steels," METALS AND ALLOYS, Vol. 9, August 1938, page 207). In 1929 this proportion was only 1.68 per cent.

Much of this expansion is due to the increased demand for the so-called "stainless steels" practically all made in the electric furnace. The output of stainless steel ingots in 1937 was 17.1 per cent of the electric ingot output. In 1934, the percentage was 14.3 per cent.

In the 25 years since its early inception in the United States, the American electric steel industry has advanced with remarkable strides until today it is recognized as a major phase of the steel industry. It is responsible for the production of most high-grade and special steels, displacing crucible steel. Only 16 years ago, over 42,100 tons of crucible steel ingots was produced—in 1937 the total was only 934 tons.—E. F. C.

Manganese Ore

We hear much spasmodically of the large resources of metallurgical manganese ore (35% Mn or more) in the United States and of the protests of an association of domestic manganese ore producers against certain alleged evils. Because of this we watch each year for the Government data on domestic ore production and each year the result is the same—insignificant domestic output in comparison with the country's consumption, judged by imports of this material.

For 1937 the total domestic production of *all* 35-percent-and-over ore was only 40,241 gross tons (32,-119 tons in 1936). By contrast the imports in 1937 were 911,922 tons or 76,000 tons per month—the largest ever recorded. In 1936 they were 813,365 tons or 67,780 tons monthly.

All this despite the "protection" of a substantial duty. But there should be no gloating—this country may some day be in such dire need of adequate supplies that regret will be poignant that large stocks were not provided against an emergency.—E. F. C.